FINAL REPORT

Vegetation Succession Following Defoliation of Forest Stands by the Douglas-fir Tussock Moth

by

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EXPANDED DOUGLAS-FIR TUSSOCK MOTH PROGRAM

FINAL REPORT

PROJECT TITLE:	Vegetation Succession Following Defoliation of Forest Stands by the Douglas-fir Tussock Moth
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DFTM ACTIVITY NUMBERS TO WHICH THE RESEARCH WAS DIRECTED:	2.1.3 and 4.1.1
NUMBER OF YEARS COVERED BY REPORT:	Approximately 3 years (3 field seasons)

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SUMMARY

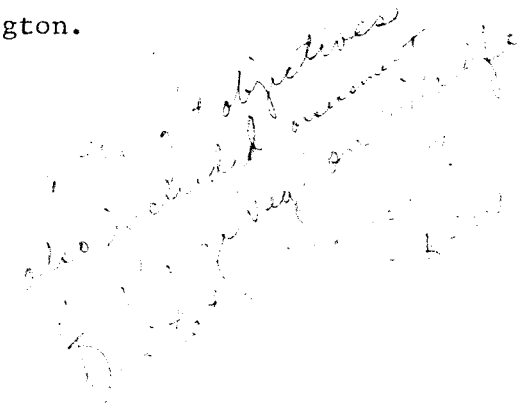
The objectives of the research project were to determine the impact of tussock moth damage in forest stands on understory and to formulate models which would predict long-term successional trends. Field studies were conducted in 1975, 1976, and 1977 in the Blue Mountains of southeastern Washington and northeastern Oregon and the Clearwater Mountains of northcentral Idaho. Studies were limited to the Abies grandis-Pachistima myrsinites habitat type. The approach to field studies involved examination of both damaged and undamaged stands. Short term effects were assessed in damaged stands which had been defoliated 2-4 years prior to the study. Models which will be used to infer long term effects were derived from data collected in undamaged stands. Canopy coverage, frequency, shrub height, understory tree density, and current year shrub and herb production were documented for 98 stands. The overstory of these 98 stands were also measured for stem density, heights, crown lengths, and diameters and stand overstory coverage and age. During the first 4-5 years following severe defoliation and high stem mortality, understory species diversity will increase significantly. Canopy coverage will increase as much as 100% with the herbaceous species accounting for most of the increase. Shade tolerant species such as Pyrola, Chimaphila and orchids will decline in abundance. Current year production of all vegetation elements will increase as much as 300%. Stands damaged to a lesser extent will show similar kinds of responses in the understory but not nearly to the degree observed in severely damaged stands. Models were developed for (1) probability of species occurrence, (2) for selected species in undamaged stands canopy coverage, (3) rooted frequency, and (4) the combined year production of species groups. These models will be linked to the prognosis model for stand development which will be the core model for projecting successional development in a forest stand.

INTRODUCTION

The purpose of this research project was to determine the probable successional pattern of forest vegetation following damage by the Douglas-fir tussock moth. Primary emphasis was placed on ascertaining successional relationships in understories of affected forest stands. The specific objectives are:

1. To determine the impact of tussock moth damage in the tree canopy on understory vegetation in terms of composition, structure, and productivity; and
2. To formulate models which will project probable long-term successional trends of the understory in damaged stands.

Field studies were conducted in 1975, 1976, and 1977 primarily in the northern Blue Mountains of southeastern Washington.



METHODOLOGY

Hypotheses Underlying the Basic Approach to Field Studies

Studies of secondary succession have generally followed two widely acceptable approaches. One is simply the long-term observation of stands following disturbance and formulation of rather precise models based on these observations. The models can then be applied to areas of similar disturbance and site characteristics. The second approach involves inferences of successional trends based on the study of many stands which approximate time points in a chronosequence of successional stages. This approach provides less exact information within a shorter period of study as to the nature of succession and encompasses a greater degree of variation which often results in models that are acceptable over a much wider geographical area. In light of the short-term objectives of the DFTM program and the need to link all successional models to the stand prognosis model for stand development (Stage 1973) which will be used to project consequences of tussock moth defoliation, the inference approach was considered the only feasible means of attaining the desired information.

Two basic suppositions were made in the proposed approach to modeling of succession. First, it was assumed that tussock moths would cause damage only to the coniferous overstory and understory trees of a forest stand and that non-coniferous understory defoliation would not result from occurrence of the insects. Secondly, it was hypothesized that ecologic conditions created by tussock moth modification of the overstory are relatively similar to conditions found in undamaged stands having similar overstory structures. Modification of overstory structure by the tussock moth will result primarily in changing light, soil moisture and soil nutrient levels to which the understory will respond. This response will be in the form of changing composition and

structure to favor opportunistic species. The prevalence of these species can be predicted from studies of undisturbed stands having similar structural characteristics, thus similar ecologic conditions as those which have undergone change due to tussock moth defoliation. By studying stands which represent time points in the progressive succession of a specific type of vegetation, the successional roles of these species can be ascertained. Inferences made from undamaged stands must be restricted to environments which will support similar vegetation associations and have similar successional seres.

Study Area

1975 field studies were conducted entirely within the northern Blue Mountains of southeastern Washington. This area has sustained moderate to severe defoliation over relatively large areas of Pseudotsuga menziesii, Abies grandis and Abies lasiocarpa habitat types during the period 1970-1973. Stand selection was limited to vegetation of the Abies grandis-Pachistima myrsinites habitat type (Daubenmire and Daubenmire 1968). Earlier studies by Head (1976) indicate that vegetation of this habitat type is one of the most susceptible to tussock moth infestations. Fifty-five stands were sampled during the 1975 field season. Forty-six stands were specifically selected to represent undamaged vegetation varying in age and structural features to use in the inference study. Nine stands were selected to represent DFTM damage conditions and seven as permanent plots which can be studied over longer time periods. All the study sites were located within areas which had generally been infested by tussock moth.

Field studies in 1976 were extended into the Clearwater Mountains of northcentral Idaho where a limited amount of tussock moth activity had been reported (Tunnock 1973). Twenty stands representative of the Abies grandis-Pachistima myrsinites habitat type within the Clearwater District of the Nezperce National Forest were sampled. Study emphasis was placed on docu-

menting the relationship between overstory structure and understory production (Pyke 1977). In addition, nine stands which had been studied in 1975 in the Blue Mountains were sampled for understory production.

In 1977, field studies were conducted in the southern Blue Mountains on both damaged and undamaged stands of the Abies grandis-Pachistima habitat type. Information from twenty new stands were added to the data base for the Blue Mountains. Intensive production sampling was carried out on most of the 1975 plots.

Sampling Procedure

Understory: Within each stand to be sampled, a circular 375m^2 macroplot was established (Fig. 1). Four 10m transects were run from the center to the perimeter of the macroplot for understory sampling. Two of the transects were placed perpendicular to the contour of the slope within the macroplot. The remaining two transects were placed at right angles to these transects. Ten 2 x 5 dm microplots were placed at 1m intervals along each of the four transects for collection of canopy coverage and rooted frequency data on all vascular understory plant species and density counts of coniferous tree reproduction less than 1.4cm tall (Daubenmire 1968). Density counts were divided into trees less than 5cm tall and trees 5cm to 1.4m tall. A single estimate of average shrub height was recorded for each shrub species over the entire macroplot. All species not found in the microplot sample but present within the macroplot boundary were recorded.

Two different sampling techniques were used to assess understory current year productivity. In 1976, understory production was determined by modifying a method developed by W. F. Mueggler (1976). Ten 4.8 $ft.^2$ circular production microplots were placed in a stratified-random fashion within each macroplot. Two, two-man teams were used in sampling with each team clipping one production microplot and estimating four microplots as a percentage of the clipped microplot.

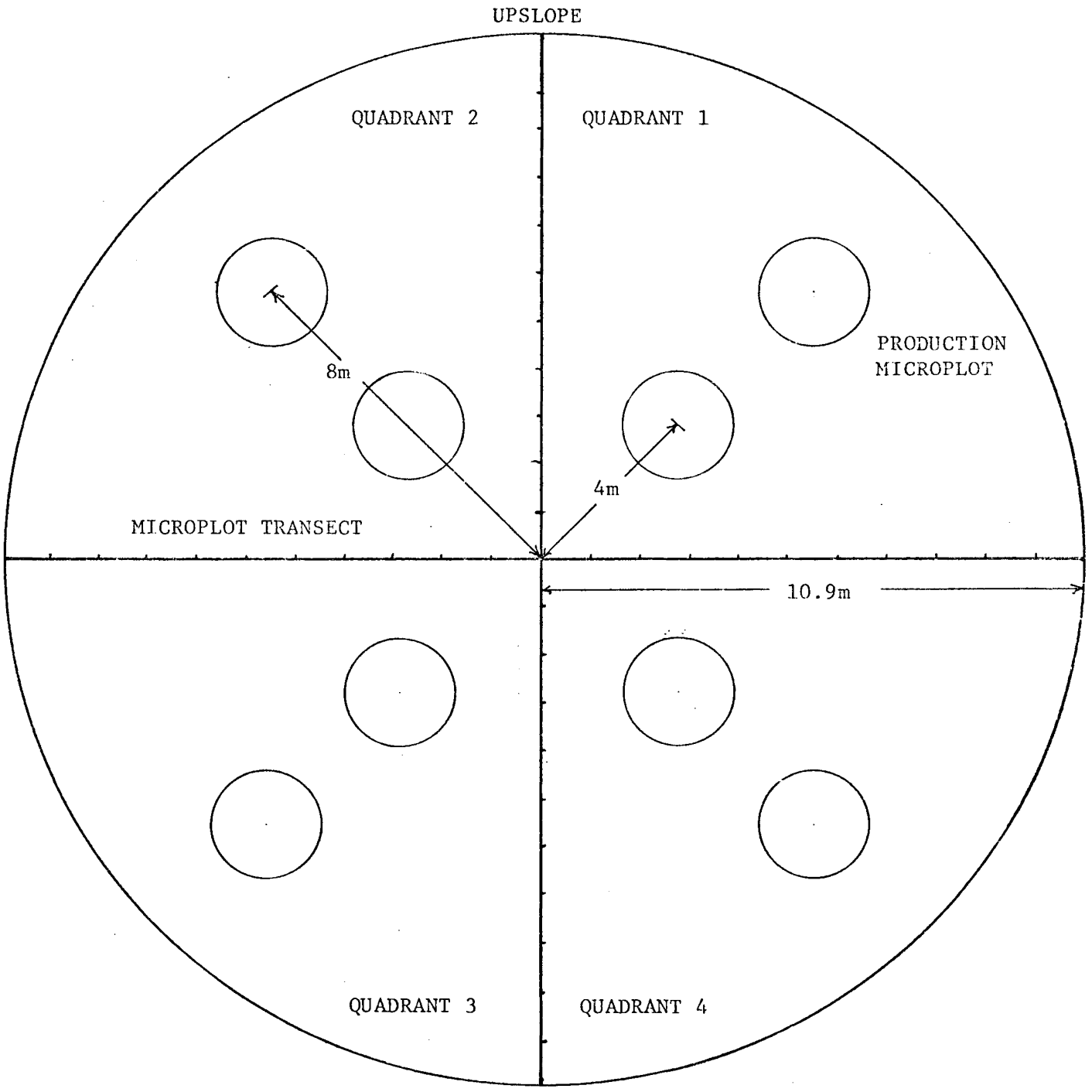


Fig. 1. Macroplot used in understory sampling.

Estimation error was assessed by clipping all microplots after estimation for 10% of the macroplots. An equation was derived which adjusted the estimation prior to calculating the production for each plot. The production was sampled between August 9 and 17, 1976, which was considered as the period of maximum above-ground production for the year. Total current year's growth was clipped and estimated for herbage and browse between the forest floor and 1.68m in height and separated into the following classes: (1) selected species chosen on the basis of importance as livestock and big game forage and browse (Acer glabrum, Amelanchier alnifolia, Berberis repens, Lonicera utahensis, Vaccinium membranaceum and the genus Carex); (2) tall shrubs (excluding those listed as selected species); (3) low shrubs (excluding Berberis repens); (4) forbs; (5) graminoids (excluding Carex); and (6) annuals. Clippings were air-dried in a forced-air cabinet for three days, oven-dried for 12 hours at 60°C and weighed.

In 1977, understory production was sampled by two, two-man teams from June 15 to August 15. Adjustments were made in the sampling schedule among sites to accomodate phenological development. Production for all stands represents maximum growth for the year. Two 4.8 ft.^{2} circular production microplots were placed systematically within each quarter of the macroplot (Fig. 1). The microplots were located along a line equidistant from the canopy coverage and frequency transects and at 4 and 8m from the plot center. Total current year's growth was clipped from all microplots between the forest floor and 1.68m in height and separated into the following classes: (1) production from each shrub species kept separate; (2) Gramineae species; (3) Cyperaceae + Juncaceae species; (4) perennial forbs; and (5) annuals. The total volume of forest floor debris within each microplot was estimated. Clippings were placed in storage to air-dry until after the field season, then dried in a forced air cabinet for 16-18 hours at 55°C and weighed. The results of the two drying procedures used are essentially the same.

Overstory: For all live trees greater than 1.4m in height within the macroplot, DBH, height, and height to base of live crown were recorded by species. The number of dead standing trees were counted and where possible, the species determined. Crown coverage of the overstory was measured with a densiometer placed at 1m above the ground at the center of the plot (Lemmon 1956). Hemispherical photographs were taken of the overstory at the same point as the densiometer readings as a second measure of canopy cover and to assess solar radiation-canopy interactions (Anderson 1964, 1971). Increment cores were taken from 4-8 dominant and codominant trees at breast height within the plot to determine stand age.

In stands which had been defoliated by tussock moths, an evaluation of canopy defoliation for each live tree was made by assigning each vertical third of the crown to one of the following defoliation classes:

Defoliation Class No.	Category	Description
1	no defoliation	no visible evidence of defoliation
2	light defoliation	visible defoliation but most older needles retained
3	moderage defoliation	defoliation evident, up to 50% of older needles lost
4	severe defoliation	only current year needles visible

Damage classes which reflect total impact on the coniferous tree component of the stand were assigned after evaluation of the data collected from each stand and are defined as follows:

Damage Class	Category	Description
1	no damage	no stem mortality which can be attributed to tussock moth defoliation, no visible evidence of defoliation
2	light damage	mortality of one stem or less; light defoliation in upper two-thirds of crown or moderate in top third

Damage Class	Category	Description
3	moderate damage	mortality of less than one-half of basal area; light to heavy defoliation in all portions of crown
4	severe damage	mortality of more than one-half of basal area; severe defoliation in all portions of crowns of living stems

Site Characteristics: Aspect, slope steepness, elevation, slope configuration and slope position was determined for each study site.

Photographs: Color photographs were taken of all stands. Black and white phorographs however were taken of selected stands only.

Species Identification: All plant species were identified using Hitchcock et al. (1955, 1959, 1964, 1969) and Hitchcock and Cronquist (1973). Nomenclature follows Hitchcock and Cronquist (1973). Specimens of species collected for identification have been deposited in the research herbarium of the Department of Forestry and Range Management, WSU.

Data Analysis: Statistical relationships were examined using the 1972 and 1976 versions of the Statistical Analysis System (Barr and Goodnight 1972, 1976) and the RISK Program (Hamilton 1974). Tabulation and summarization of the vast amount of understory composition, species coverage, and species frequency data was completed by means of four computer programs developed by Bryan Bremner and Mei Wang, Computer Programmers in the Department of Forestry and Range Management and Department of Computer Science respectively. Classification analyses were also conducted using the Numerical Taxonomy System of Multivariate Statistical Program package (Rohlf, Kishpaugh, Kirk 1974).

Description of the Data Base

The data base is composed of information from 58 undamaged and 20 damaged stands in the Blue Mountains of southeastern Washington and northeastern Oregon and 20 stands in the Clearwater Mountains of northcentral Idaho. It is important

to stress that the data is directly applicable only to the Abies grandis - Pachistima myrsinites habitat type of this region as described by Daubenmire and Daubenmire (1968). A list of the specific variables for which information has been tabulated at this time for all or certain stands examined during the course of this study is as follows:

1. Understory
    a. average canopy coverage percentage for all species
    b. rooted frequency for all species
    c. canopy frequency for all species
    d. average shrub height by species
    e. summed canopy coverage percentages for various growth form species groups (shrubs, graminoids, perennial forbs, annuals, understory trees)
    f. current year production for selected species and growth form species groups
2. Overstory
    a. age (maximum based on oldest tree and average based on 4-8 dominant and codominant trees in stand)
    b. density (total and by species)
    c. diameters at breast height (a sum for total stand and by species)
    d. basal area (total and by species)
    e. height of stand (an average based on all trees > 1.4m ht.)
    f. average length of live crown in stand
    g. crown closure (total canopy coverage of overstory)
    h. probability of diffuse and direct solar radiation penetrating canopy
    i. dead stem density
3. Physical Environment
    a. aspect of slope

b. slope steepness

c. elevation

d. slope configuration

e. position of macroplot on slope

4. In Damaged Stands

a. relative degree of defoliation

Analysis of the data base will continue as manuscripts are prepared for publication.

RESULTS

This report stresses the studies conducted in the Blue Mountains and includes only the understory production - overstory relationships for the Clearwater Mountains of northcentral Idaho. All data and interpretations are for non-salvaged stands where extensive soil disturbance will not significantly alter understory response. All tables in this report have been placed in the appendix for ease of organization. Where pertinent, data will be abstracted from the tables to illustrate points made in the text.

A summary of the associated site characteristics of the stands examined in the Blue Mountains is given in Table 1. No effort was made in the initial stand selection to obtain a sample across the full spectrum of site conditions occupied by the Abies grandis - Pachistima association. It is obvious from Table 1, however, that a wide range of sites were sampled. In general, the sites span the entire elevational range of grand fir in the Blue Mountains, particularly in the northern portion of the mountain range. As expected, aspect and slope gradient were the site variables which consistently accounted for a significant amount of variation in the majority of the regression modelling. Slope configuration, position of macroplot on slope, and elevation do not appear in preliminary analysis to be highly correlated with vegetation composition and structure.

A list of all plant taxa identified among the Blue Mountain stands is given in Table 2. Constancy values given in the table refer to the percentages of macroplots in which the taxa were found. The list contains 188 taxa consisting of the following: six trees, 38 shrubs, 18 perennial graminoids, 110 perennial forbs, and 16 annuals.

Vegetation of Defoliated Stands

As previously mentioned, 20 damaged stands were examined during the course of the study. These stands had undergone defoliation by tussock moths two to

four years prior to the vegetation studies. Specifically, the lightly damaged stands were sampled two years after defoliation and the moderately and severely damaged stands were sampled two to four years after defoliation had taken place. Most of the comparisons made in this section are not considered extremely precise because of the small sample and the amount of variation encountered, but indicate general events that can be expected to happen in the understory following defoliation of the overstory.

Overstory Characteristics: A comparison of selected overstory characteristics among severely, moderately, lightly and undamaged stands is shown in Table 3. Ten undamaged stands were selected from the total 58 for all comparisons of damaged to undamaged stand conditions. The selection was based on cluster analysis of the combined data for damaged and undamaged stands. The principal variables used in the cluster analysis were live and dead tree density, live and dead tree basal area, and average tree height. These combined variables were used in an effort to select stands that were somewhat comparable in structure prior to defoliation impact. The data for stem mortality and dead basal area in the stands illustrates the differences between damage classes as defined in this study. It is important to point out that what we considered moderate damage may be considered severe damage by other scientists. Our interpretation of damage included assessments of the understory response as well as impact on the tree component of the stand.

Understory Composition, Species Canopy Coverage and Frequency: Tables 4-7 show various comparisons of species composition, canopy coverage and frequency between damage classes.

The total number of species observed per macroplot sample among moderate, light and undamaged stands were very similar, averaging 26-29 species per plot (Table 4). The only major difference between these plots was the presence of annuals in the moderate damage plots. A small but significant average increase

in numbers of species (36) is evident for severely damaged plots. Perennial grasses, perennial forbs and annual forbs account for this increase in diversity.

Summed canopy coverage values for growth form species groups in the vegetation of the damage classes are shown in Table 5. A generalization of the data is illustrated in Fig. 2. Little difference is evident in understory tree cover among the damage classes, however a significant increase in total shrub cover is obvious for severely damaged stands. Shrubs which are least preferred as browse by ungulates appear to account for the major difference between damage classes. Total herbaceous coverage distinctly increased concomitant with damage class. This overall increase can be attributed to increases in coverage for perennial grasses, perennial forbs, and annuals (Fig. 2). Perennial grasses and annuals had the largest percentage increase. Perennial forb cover in the light to severe damage classes were quite similar with averages ranging from 76% to 88%. These averages are nearly a 100% increase over the average perennial forb cover calculated for undamaged stands. The trend toward increased abundance of understory vegetation is evident in the total coverage values shown in Table 5 and Fig. 2.

Species composition of the various stands representing the damage classes is given in Table 6. The following species appear to show the greatest response to overstory modification by tussock moth defoliation:

Shrubs: *Ribes lacustre*

Rubus spp.

Rubus parviflorus

Sambucus cerulea

Symphoricarpos albus

Graminoids: *Bromus vulgaris*

Carex spp.

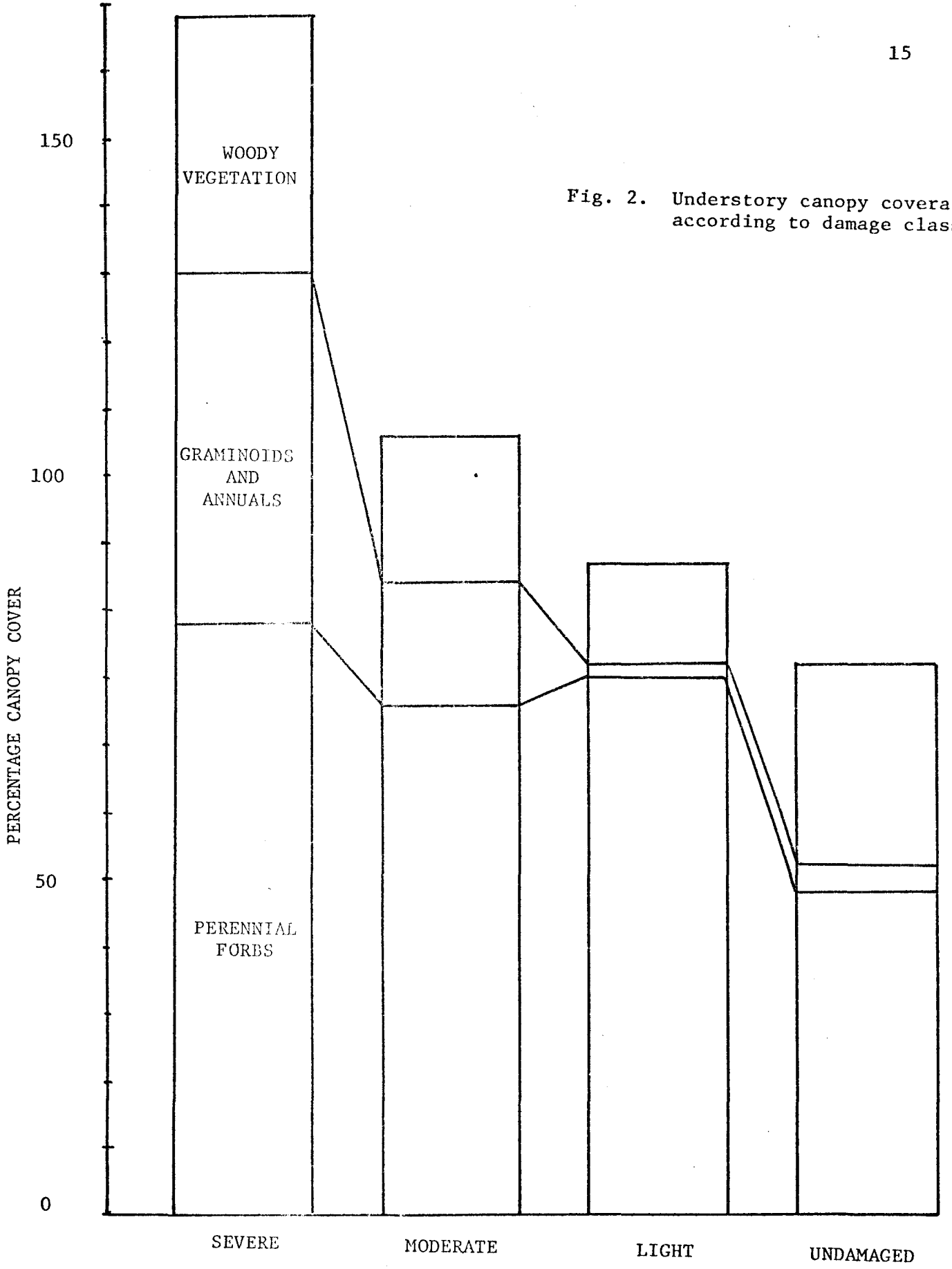


Fig. 2. Understory canopy coverage according to damage classes.

	Festuca occidentalis
	Festuca subulata
	Luzula campestris
Perennial Forbs:	*Adenocaulon bicolor*
	Astragalus canadensis
	Cerastium vulgatum
	Circaea alpina
	Cirsium spp.
	Epilobium spp.
	Galium triflorum
	Mitella stauropetala
	Osmorhiza chilensis
	Stellaria media
	Taraxacum officionale
	Tiarella trifoliata
	Tragopogon dubius
Annuals:	*Epilobium paniculatum*
	Galium aparine
	Lactuca serriola
	Montia spp.

Three severely damaged stands were located and sampled in the Little Tucannon drainage in the northern Blue Mountains in 1975. These plots were permanently marked for resampling purposes at later dates. In 1977, the plots were again measured. A comparison of the 1975 and 1977 measurements is presented in Table 7. All efforts were made in 1977 to sample exactly the same transects established in 1975.

Generally, the same shrub species indicated earlier as rapidly responding

species increased in canopy coverage from 1975 to 1977. Only Ribes lacustre and Symphoricarpos albus increased in rooted frequency. Festuca occidentalis was the only graminoid to show a significant increase over the two year period. The forbs that showed the greatest increase were Clintonia uniflora, Tiraella trifoliata, Galium aparine, and the Montia spp. Galium triflorum and Linnaea borealis did not change significantly in canopy coverage but did increase in rooted frequency between 1975 and 1977. This suggests that the species are still increasing in density and may at some point in time again increase in canopy coverage in the stands. Examination of table 7 will show that a number of species had similar responses of increased frequency but insignificant increases in canopy coverage.

Species which significantly declined in dominance and abundance between the two sample periods were: Chimaphila umbellata, Rosa gymnocarpa, Arnica cordifolia, Goodyera oblongifolia, Pyrola secunda, Epilobium paniculatum, and Lactuca serriola. The last two species listed are annuals and apparently are opportunistic species which establish early in succession then decline rapidly.

The canopy coverage of all understory components increased between the two sampling periods as follows:

	1975	1977
Understory trees	T%	0.3%
Total shrubs	27%	36%
Graminoids	8%	20%
Perennial forbs	74%	99%
Annuals	34%	40%
Total herbaceous	116%	159%
Total cover	143%	195%

Graminoids and perennial forbs showed the greatest increase in canopy coverage of all components.

Current Year Production of Understory: A comparison of understory current year production among severe, moderate, light, and undamaged stands is given in Table 8. Fig. 3 illustrates data from the table expressed in Kg per hectare for woody and herbaceous species in the understory. The most obvious difference in production is between severe and all other damage classes, with over a 3-fold increase in production. Both shrub and herbaceous species groups account for the very large difference in production. The allowable forage crop which is that portion of the current year's vegetation growth which can be utilized by animals without overuse is illustrated by the curve in Fig. 3. Severely damaged stands may produce as much as 5 times the quantity of forage over undamaged stands.

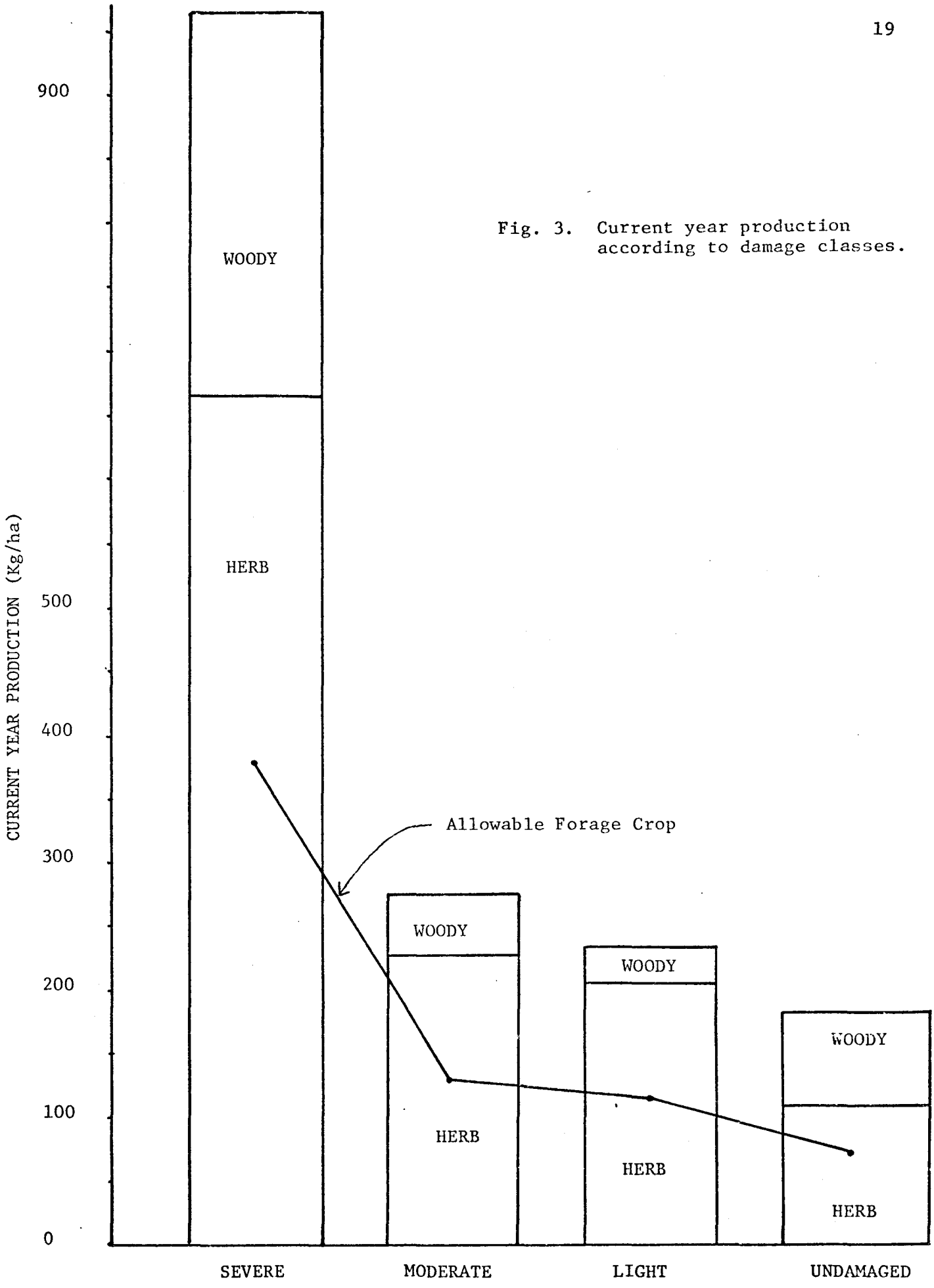


Fig. 3. Current year production according to damage classes.

Successional Models

Conceptual Basis for Models: The prognosis model for stand development (Stage 1973) will be the core model of the system which will project successional development in a forest stand. The prognosis model will be the primary generator of overstory data for the component understory models reported herein. An information passage flow chart is illustrated in Fig. 4 for the system. The prognosis model will, after interaction with the insect model, make a prognosis of the course of development that a tussock moth infested stand would be expected to follow. For each time point described by the prognosis model, understory conditions can be predicted by the component understory models. These models will be linked directly to the prognosis model. It is important at this point to identify the limitations of the understory models:

1. With the exception of the understory production models for the Clearwater Mountains, the models were developed from data collected in the Blue Mountain Region;
2. The models portray understory-overstory relationships only for the Abies grandis-Pachistima habitat type. It is not known to what extent these models may apply to other habitat types which support the Pachistima union and regions outside the study area. All stands studied were undamaged.
3. The models apply only to stands that are approximately 40 years of age and older. From this time point on, it has been our observation that understory diversity and structure is determined primarily by overstory structure. Long term successional changes may be taking place but are not easily identified. Any obvious successional change in the understory will be a direct

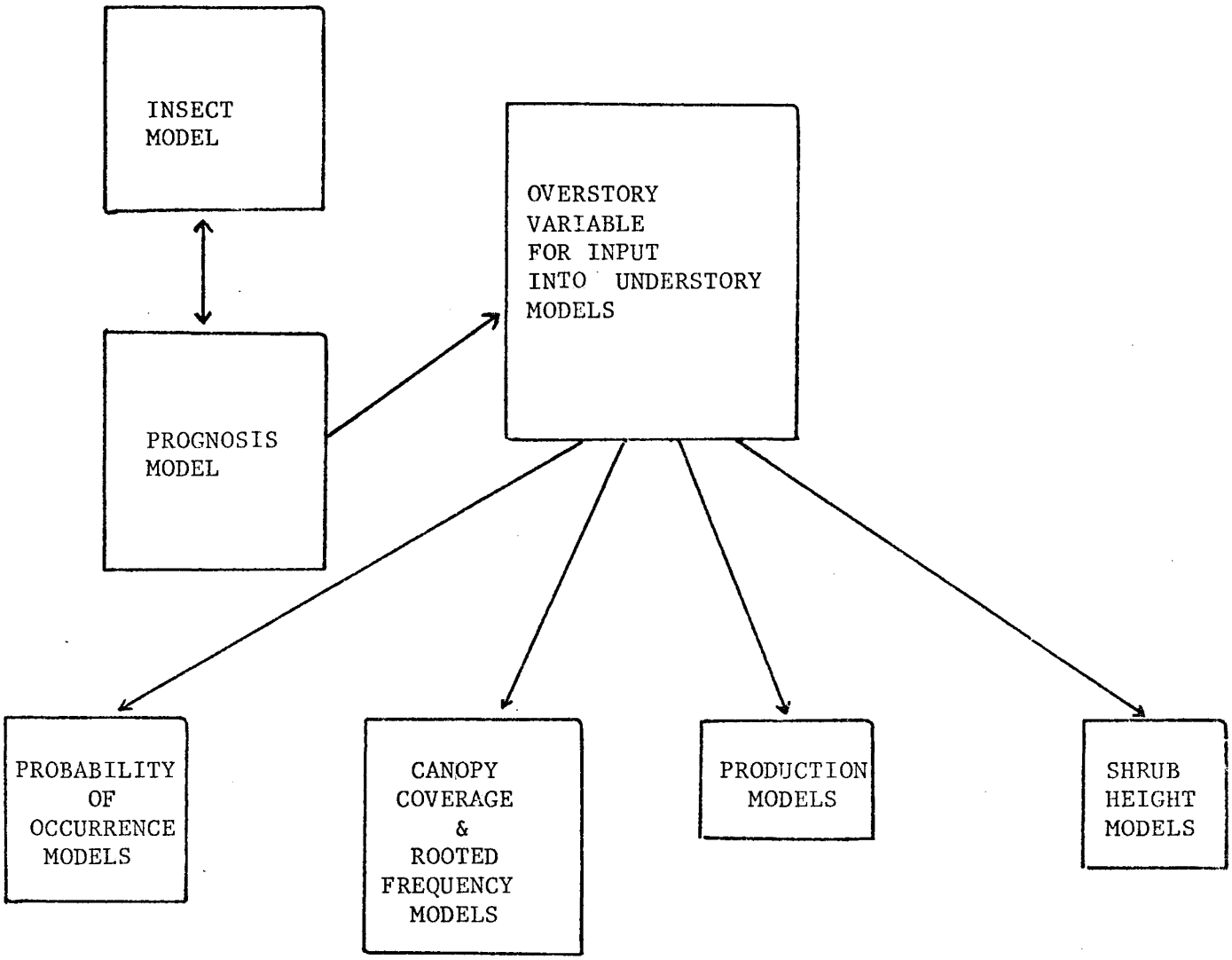


FIG. 4. Information passage flow chart showing relationship of understory models to prognosis model.

result of overstory successional change. Salvage logging disturbance factors have not been included in the models.

4. In all of the understory models for the Blue Mountains, overstory canopy coverage (syn crown closure, crown density) was not included as a variable. Overstory canopy coverage, however, was included as an independent variable in the Clearwater Mountain models. These models are subject to revision. We found this variable to be significantly correlated to diversity and structure of the understory. The variable was excluded because the prognosis model does not generate directly canopy coverage information. The model does, however, generate information about crown competition factors which may be related indirectly to crown cover. This relationship will be researched.

Probability of Occurrence Models: The probability of an understory species occurring under stand conditions predicted by the prognosis model were determined for 21 shrubs, 5 graminoids, 45 perennial forbs, and 3 annual forbs. Only species which had constancies of approximately 10% or greater in undamaged stands were selected. Of the 188 species encountered in the study, only 74 meet this requirement. These species are identified in Table 2 with an asterisk.

The RISK procedure was used to develop the probability models (Hamilton 1974). The program uses an algorithm for fitting the logistic function of the relationship between a dichotomous dependent variable and a number of independent variables (Walker and Duncan 1967). Non-linear regression coefficients are calculated for the independent variables. The equation for the logistic function in metric notation is

$$\hat{P} = [\ 1 + \exp(-x^{1}\beta)\ ]^{-1} + \varepsilon$$

where

$\hat{P}$ = estimate of probability of the occurrence of a species

X = vector of independent variables

β = vector of regression coefficients

$\varepsilon = 0$

The models were developed using the following independent variables:

(1) cos(aspect) x tan(slope),

(2) sin(aspect) x tan(slope),

(3) tan(slope),

(4) total tree stem density in macroplot,

(5) sum of diameters of all trees in macroplot,

(6) height(m) to base of live crown,

(7) length(m) of live crown.

Correlation analysis was employed in the selection of these variables. The variables expressing the relationship between slope and aspect were incorporated as suggested by Stage (1976).

The models are in computer files at Washington State University. The models are to voluminous to place in this report but have been made available to the programers that are linking all component models to the prognosis model. Four probability curves for species have been included in this report to illustrate the models (Fig. 5-8).

Canopy coverage and Frequency Models: Linear multiple regression models for 34 species canopy coverage and rooted frequency characteristics under various stand conditions were developed (Table 9 and 10). The lack of sufficient cover and frequency data for all 74 species included in the probability modeling restricted our regression modeling efforts to only 34 species. The independent variables employed in the models are described in Table 10. The models were based on data from 58 stands.

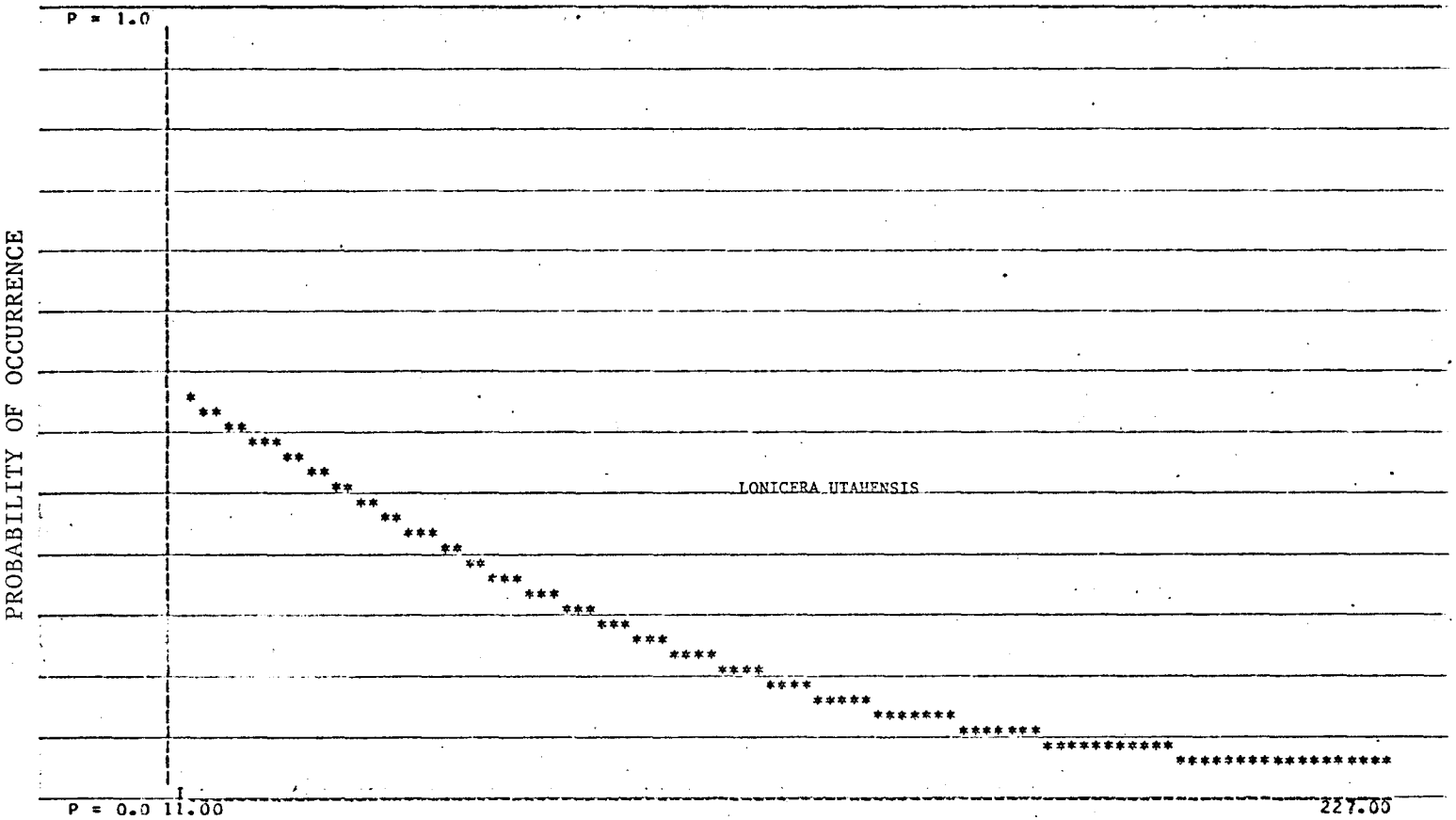


Fig. 5. Probability curve of Lonicera utahensis occurrence according to stem density of overstory.

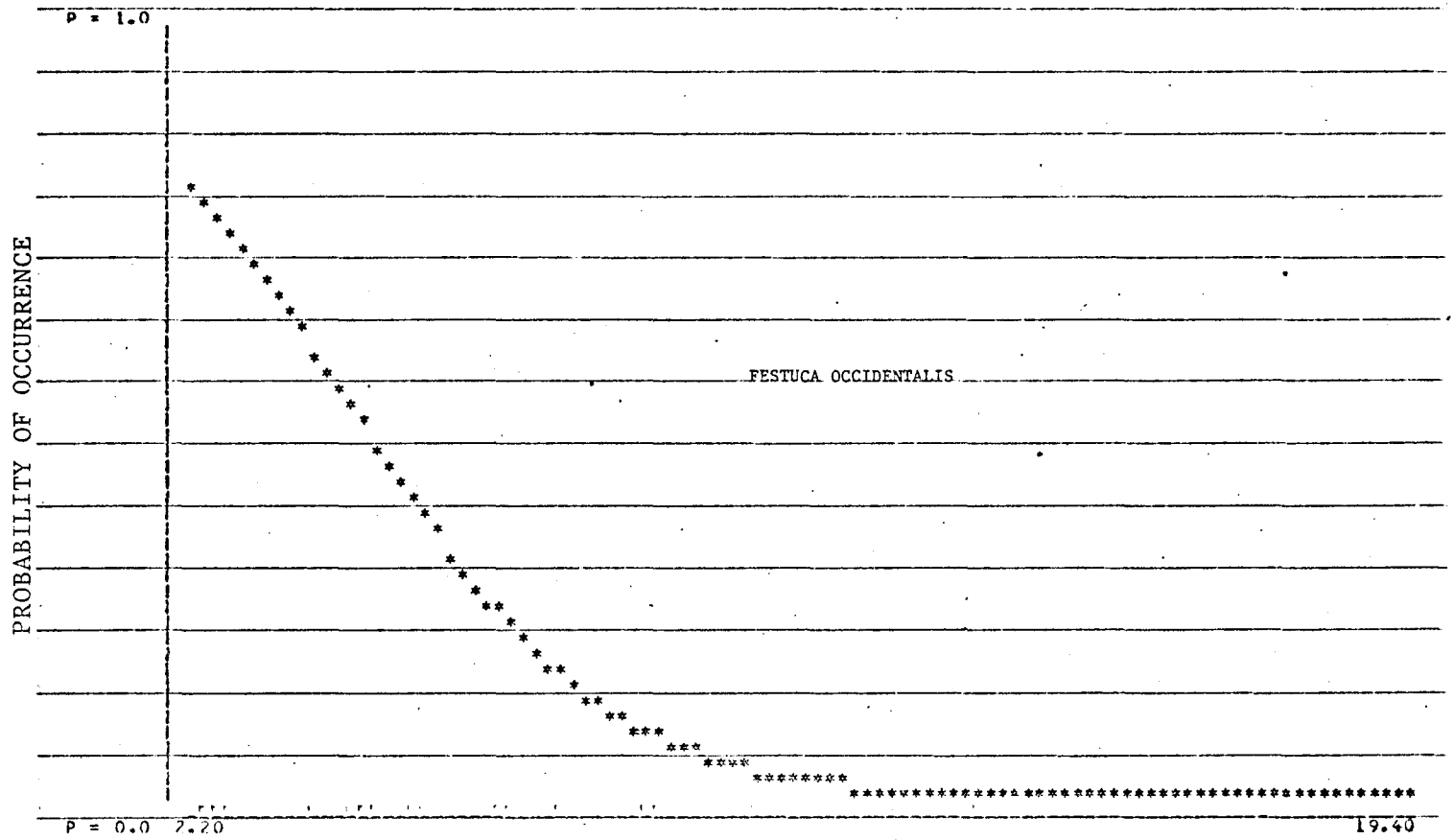


Fig. 6. Probability curve of Festuca occidentalis according to average crown length in the overstory.

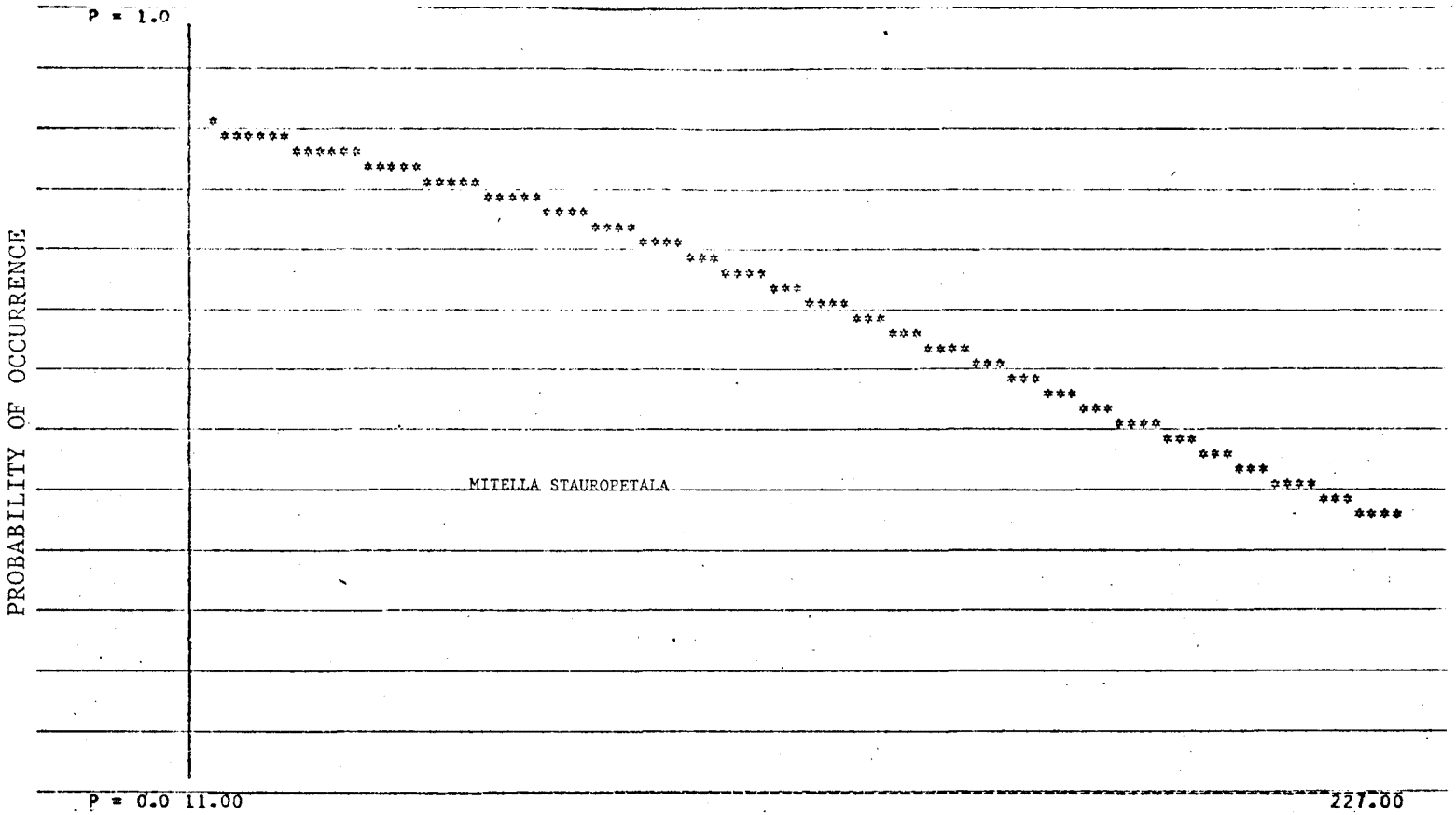


Fig. 7. Probability curve of Mitella stauropetala according to stem density.

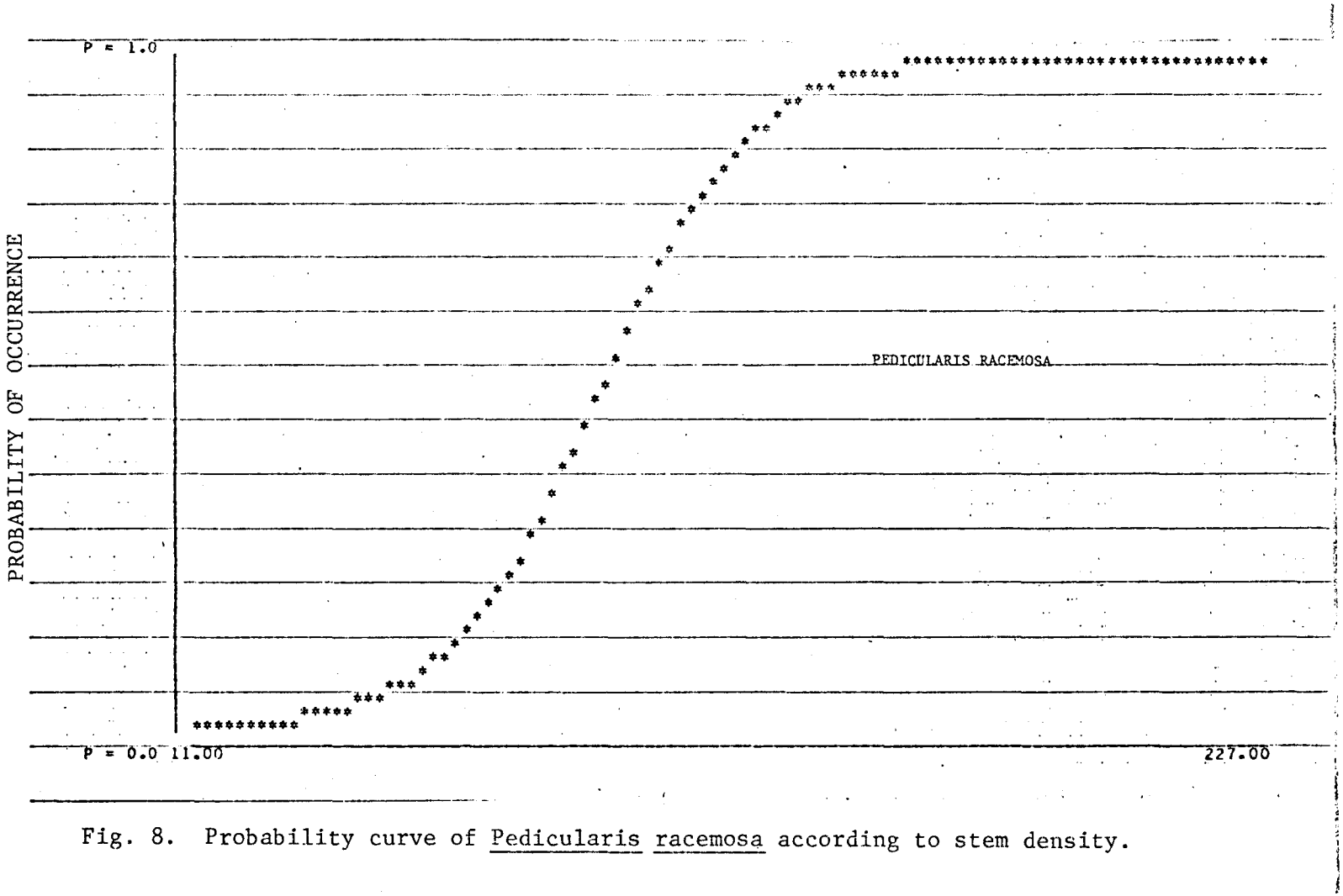


Fig. 8. Probability curve of Pedicularis racemosa according to stem density.

Understory Production Models: Linear multiple regression models for understory production in the Blue Mountains are presented in Table 11. Independent variables are described in Table 12. No specific models for individual species have yet been developed, however, models for 12 vegetation components of more general interest were determined from data for 47 stands. The allowable forage crop model provides the means of assessing utilizable production by ungulates in the understory. This component includes highly preferred shrubs, moderately preferred shrubs and total herbage production.

The production models for the Clearwater Mountains are presented in Table 13. The table was taken from a thesis written by Pyke (1977). The thesis is attached to this report. All the models contain overstory canopy coverage as an independent variable, consequently the models are subject to revision. A model for graminoid production was not developed because of the lack of correlation with overstory structure. Efforts to develop such a model are being planned. These models are being re-examined in light of the need to link them to the prognosis model. Additional descriptions of the models are presented by Pyke (1977).

Shrub Height Model: A shrub height model will be developed in the near future and added as one of the component models. This model will aid in assessment of potential competition to tree regeneration following overstory manipulation.

CONCLUSIONS REGARDING TUSSOCK MOTH DEFOLIATION IMPACT ON UNDERSTORY

1. The following events can be expected to take place in the understory of tussock moth damaged, non-salvaged stands during the first 4-5 years following defoliation:
   a. a small but significant increase in species diversity in severely damaged stands, but little increase in stands that are damaged to a lesser degree;
   b. as much as a 100% increase in total understory cover with perennial grass and forb and annual species accounting for most of the increase;
   c. some shade tolerant species such as Pyrola, Chimaphila and Orchids will decline;
   d. current year production of all vegetation elements will increase as much as 3-fold in severely damaged stands; relatively small change to take place in lesser damaged stands.

PROBLEMS ENCOUNTERED IN CONDUCTING RESEARCH

The major problem encountered was locating damaged stands which had not been salvaged logged. Extensive salvage operations were immediately initiated by the Forest Service throughout most tussock moth infested areas.

Identifying lightly defoliated stands after tussock moth infestation was an additional problem. Defoliation of the trees frequently masked previous defoliation evidence in the stand.

During the third field season, infra-red color aerial photographs and the best Forest Service maps of the defoliated areas in the Blue Mountains were employed to identify defoliated stands. This did not prove as valuable as originally thought, but did help in the location of additional severely damaged stands in the northern Blue Mountains.

Production measurements for 1977 may have been influenced to an unknown degree by the drought conditions of the year. It is my opinion that production was influenced little based on my experience in the region over the last 10 years. Phenological development was much more rapid, but in my judgement, understory production was reduced no more than 10-15%. We do not have any means of assessing this variation.

COOPERATION AND COORDINATION

Close coordination was established with Al Stage in developing the concepts for successional modeling and the ways in which the models would link to the prognosis model. It was absolutely essential that we use variables which could be generated by the prognosis model.

Bob Heller provided us with a set of infra-red color aerial photographs for the 1977 field season and suggested approaches in field sampling using the photographs.

Personnel of the Umatilla and Nezperce National Forests assisted us in locating specific stands and areas for study with the various districts, provided maps, management history, and immediate management plans for potential study sites.

MANUSCRIPTS AND REPORTS

1. The following reports were presented during the course of this study:
    a. A report delievered by B. Zamora at the Forest Insect and Disease Management Workshop, Albuquerque, New Mexico, on methodology employed in this study. No written report submitted to the workshop.
    b. A paper presented on the preliminary production models at the

Society for Range Management annual meeting, Feb. 1977, by D. Pyke and B. Zamora. Abstract attached to this report.

2. The following is a thesis prepared by D. Pyke in 1977 (a copy is attached):

   Pyke, D.A. 1977. Relationships between overstory structure and understory production in the Abies grandis - Pachistima myrsinites habitat type of northcentral Idaho and southeastern Washington. M.S. Thesis (Forestry and Range Manage.), Washington State University, 55 pp.

3. Rodrick Clusnitzer will complete a thesis on understory production-overstory structure for the Abies grandis - Pachistima habitat type in the Blue Mountains by June 1, 1978. This thesis will contain the final evaluation and modeling of understory production for the Blue Mountains.

4. The following are topics for which manuscripts are planned:

   a. a conceptual basis for modelling of understory succession in forest stands;

   b. understory-overstory relationships in the grand fir habitat type of the northern Blue Mountains;

   c. understory production-overstory structure relations in grand fir habitat types of the Clearwater Mountains, northcentral Idaho;

   d. understory production-overstory structure relations in the grand fir habitat type of the northern Blue Mountains.

RECOMMENDATIONS FOR FUTURE RESEARCH

The models described in this report have not been extensively tested nor validated. Additional research must be conducted to refine and verify all models. Additional efforts must be made to expand the data base to include other habitat types and regions. Some means must be found to generate overstory canopy coverage information for use in the understory models. This would improve the prediction power of the understory models considerably. Future research on shrub and herb production should be designed to include at least 2-3 years of sampling of specific sites. This will then give some measurement of annual variation. Major research emphasis should be placed on understory response for various stand management alternatives and silvicultural treatments.

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APPENDIX A

Table 1. Summary of site characteristics for severely, moderately, lightly and undamaged stands examined in the Blue Mountains, 1975 to 1977.

Site Characteristic		Percentage of stands occurring in each site characteristic category: Severely Damaged n=11[1]	Moderately Damaged n=6	Lightly Damaged n=3	Undamaged n=58
Aspect:	0- 90°	64	33	67	38
	91-180°	-	17	33	21
	181-270°	9	17	-	12
	271-300°	27	33	-	29
Slope:	0-10%	-	17	-	34
	11-20%	27	-	-	7
	21-30%	-	50	-	17
	31-40%	9	33	67	7
	41-50%	-	-	-	7
	51-60%	27	-	33	10
	61-70%	27	-	-	9
	71-80%	9	-	-	3
	>80%	-	-	-	6
Slope Configuration:					
	straight	27	17	33	29
	convex	-	33	33	19
	concave	27	17	33	14
	undulating	46	33	-	38
Position on Slope:					
	bench top	-	-	-	7
	ridge top	-	17	33	26
	upper 1/3	18	50	33	27
	middle 1/3	45	-	33	14
	lower 1/3	37	33	-	26
Elevation:[2]					
	800+m	-	17	-	2
	900+m	82	17	-	10
	1000+m	-	-	-	17
	1100+m	-	17	-	17
	1200+m	18	32	-	15
	1300+m	-	-	-	12
	1400+m	-	-	100	21
	1500+m	-	17	-	2
	1600+m	-	-	-	4
	1700 m				

[1] n = number of stands

[2] each elevation listing refers to the corresponding 100 m interval.

Table 2. A list of all species and their constancy values for the Blue Mountain study plots of damaged and undamaged stands.

	Species Symbol	Scientific Name	Constancy (%) Damaged n=20	Undamaged n=58
TREES				
	ABGR	Abies grandis	60.0	98.3
	LAOC	Larix occidentalis	20.0	12.1
	PICO	Pinus contorta	-	8.6
	PIPO	Pinus ponderosa	-	13.8
	PIEN	Picea engelmannii	5.0	25.9
	PSMEG	Pseudotsuga menziesii glauca	20.0	20.7
SHRUBS				
*	ACGL	Acer glabrum	75.0	44.8
	ALNUS	Alnus spp.	5.0	5.2
*	AMAL	Amelanchier alnifolia	60.0	65.5
	ARUV	Arctostaphylos uva-ursi	-	8.6
	BENE	Berberis nervosa	-	5.2
*	BERE	Berberis repens	20.0	41.4
	CESA	Ceanothus sanguineus	5.0	-
	CEVE	Ceanothus velutinus	-	1.7
*	CHME	Chimaphila menziesii	25.0	56.9
*	CHUM	Chimaphila umbellata	50.0	87.9
	CLCO	Clematis columbiana	-	3.4
	COCO2	Corylus cornuta	-	1.7
*	HODI	Holodiscus discolor	35.0	6.9
*	LIBO2	Linnaea borealis	55.0	67.2
*	LOCI	Lonicera ciliosa	35.0	6.9
	LOIN	Lonicera involucrata	-	1.7
*	LOUT2	Lonicera utahensis	25.0	36.2
*	PAMY	Pachistima myrsinites	15.0	19.0
	PECO	Penstemon confertus[1/]	5.0	-
	PHLE	Philadelphus lewisii	15.0	3.4
*	PHMA	Physocarpus malvaceous	-	15.5
	PRVI	Prunus virginiana	-	1.7
	RHAL2	Rhamnus alnifolia	-	1.7

Table 2. continued

	Species Symbol	Scientific Name	Constancy (%) Damaged n=20	Undamaged n=58
	RICE	Ribes cereum	-	1.7
*	RILA	Ribes lacustre	65.0	51.7
*	RIVI	Ribes viscosissimum	20.0	25.9
	ROSA	Rosa spp.	5.0	-
*	ROGY	Rosa gymnocarpa	70.0	72.4
	RUBUS	Rubus spp.	15.0	-
	RUID	Rubus idaeus	15.0	1.7
*	RUPA	Rubus parviflorus	60.0	29.3
*	SALIX	Salix	10.0	6.9
	SACE	Sambucus cerulea	20.0	-
	SARA	Sambucus racemosa	10.0	-
*	SOSC2	Sorbus scopulina	25.0	19.0
*	SPBEL	Spirea betulifolia lucida	45.0	58.6
*	SYAL	Symphoricarpos albus	55.0	37.9
*	TABR	Taxus brevifolia	35.0	24.1
*	VAME	Vaccinium membranaceum	40.0	89.7
PERENNIAL GRAMINOIDS				
	AGSP	Agropyron spicatum	5.0	-
*	BRVU	Bromus vulgaris	95.0	50.0
*	CAREX	Carex	65.0	65.5
	CAGE	Carex geyerii	5.0	-
*	CARU	Calamagrostis rubescens	25.0	17.2
	DAGL	Dactylis glomerata	-	1.7
	FEID	Festuca idahoensis	-	1.7
*	FEOC	Festuca occidentalis	80.0	53.4
	FESU	Festuca subulata	20.0	-
	KOCR	Koelaria cristata	-	1.7
	LUCA2	Luzula carpestris	10.0	-
	MESU	Melica subulata	15.0	5.2
	PHPR	Phleum pratense	-	1.7
	POCO	Poa compressa	-	3.4

Table 2. continued

	Species Symbol	Scientific Name	Constancy (%) Damaged n=20	Undamaged n=58
	POPR	Poa pratensis	5.0	3.4
	SIHY	Sitanion Hystrix	5.0	-
	TRISE	Trisetum spp.	-	1.7
*	TRCA	Trisetum canescens	5.0	17.2
PERENNIAL FORBS				
	ACCO	Aconitum columbianum	-	5.2
*	ACMIL	Achillea millefolium lanulosa	30.0	8.6
*	ACRU	Actaea rubra	15.0	15.5
*	ADBI	Adenocaulon bicolor	80.0	36.2
	AGOSE	Agoseris spp.	5.0	-
	AGGR	Agoseris grandiflora	-	1.7
	ANPI	Anemone piperi	95.0	98.3
	ANTEN	Antennaria spp.	-	5.2
	ANAN	Antennaria anaphaloides	-	3.4
	ANMI	Antennaria microphylla	-	3.4
	ANRA	Antennaria racemosa	-	1.7
*	ARCO	Arnica cordifolia	95.0	94.8
*	ARMA3	Arenaria macrophylla	95.0	70.7
*	ASCAM	Astragalus canadensis mortonii	30.0	22.4
	ASCA3	Asarum caudatum	-	3.4
	ASCO	Aster conspicuous	-	1.7
	ASIN	Aster integrifolius	-	3.4
	ATFIF	Athyrium filix-femina	-	1.7
*	AQFO	Aquilegia formosa	25.0	10.3
	BOMA	Boykinia major	-	1.7
*	CABU	Calypso bulbosa	5.0	39.7
	CAEL	Calochortus elegans	-	3.4
	CAMA	Calochortus macrocarpus	-	1.7
	CEVU	Cerastium vulgatum	30.0	-
*	CIAL	Circaea alpina	45.0	8.6

Table 2. continued

	Species Symbol	Scientific Name	Constancy (%) Damaged n=20	Undamaged n=58
	CIAR	Cirsium arvense	5.0	-
*	CIVU	Cirsium vulgare	50.0	3.4
*	CLUN	Clintonia uniflora	50.0	46.6
	COCA	Cornus canadensis	-	3.4
*	COMA3	Corallorhiza maculata	5.0	17.2
*	CYFR	Cystopteris fragilis	35.0	20.7
	CYMO2	Cystopteris montana	10.0	3.4
	DENU2	Delphinium nuttallii	-	3.4
*	DITR	Disporum trachycarpum	65.0	46.6
	EPAN	Epilobium angustifolium	10.0	1.7
*	EPGL	Epilobium glaberrimum	35.0	3.4
*	EPWA	Epilobium watsonii	25.0	5.2
	ERIGE	Erigeron spp.	-	1.7
	ERGR	Erythronium grandiflorum	-	1.7
	ERYTH	Erythronium spp.	5.0	-
*	FRVE	Fragaria vesca	80.0	62.1
*	FRFA	Frasera fastigata	-	13.8
*	GABO	Galium boreale	40.0	6.9
*	GATR	Galium triflorum	90.0	62.1
	GOOB	Goodyera oblongifolia	55.0	91.4
	HABEN	Habenaria spp.	-	3.4
	HAUN	Habenaria unalascensis	5.0	8.6
*	HIAL	Hieracium albiflorum	100.0	81.0
	HICY	Hieracium cynoglossoides	-	1.7
	HYCA	Hydrophyllum capitatum	5.0	3.4
	HYFE	Hydrophyllum fendleri	15.0	-
*	LICA3	Listera caurina	5.0	29.3
	LIRU	Lithospermum ruderale	5.0	-
	LIPA	Lithophragma parviflora	-	1.7
	LUPIN	Lupinus spp.	-	1.7
	LUAR	Lupinus argenteus	-	1.7

Table 2. continued

	Species Symbol	Scientific Name	Constancy (%) Damaged n=20	Undamaged n=58
*	LUCA	Lupinus caudatus	40.0	24.1
	LULE	Lupinus leucophyllus	-	1.7
	MEPA	Mertensia paniculata	5.0	-
	MIPE	Mitella pentandra	-	1.7
*	MIST2	Mitella stauropetala	70.0	67.2
*	OSCH	Osmorhiza chilensis	100.0	86.2
	PENST	Penstemon spp.	5.0	-
	PEAT	Penstemon attenuatus	-	3.4
	PEDE	Penstemon deustus	-	1.7
	PEVE	Penstemon venustus	-	1.7
*	PERA	Pedicularis racemosa	5.0	13.8
	PHHA	Phacelia hastata	15.0	3.4
	PHLOX	Phlox spp.	-	-
*	POTEN	Potentilla	10.0	8.6
*	POMU	Polystichum munitum	25.0	12.1
*	POPU	Polemonium pulcherrimum	25.0	32.8
	PTAN	Pterospora andromedea	-	1.7
	PTAQ	Pteridium aquilinum	15.0	5.2
	PYROL	Pyrola spp.	-	5.2
*	PYAS	Pyrola asarifolia	10.0	25.9
*	PYCH	Pyrola chlorantha	15.0	12.1
	PYMI	Pyrola minor	-	3.4
*	PYPI	Pyrola picta	10.0	27.6
*	PYSE	Pyrola secunda	55.0	79.3
	PYUN	Pyrola uniflora	-	12.1
	RANUN	Ranunculus spp.	10.0	6.9
*	RAUN2	Ranunculus uncinatus	45.0	13.8
	RUMEX	Rumex spp.	-	1.7
	RUAC	Rumex acetosella	20.0	-
	RUOC	Rudbeckia occidentalis	5.0	-
	SADO	Satureja douglasii	-	1.7

Table 2. continued

	Species Symbol	Scientific Name	Constancy (%) Damaged n=20	Undamaged n=58
	SELA2	Sedum lanceolatum	-	3.4
	SENEC	Senecio spp.	-	10.3
	SETR	Senecio triangularis	-	1.7
*	SMRA	Smilacina racemosa	35.0	15.5
*	SMST	Smilacina stellata	55.0	51.7
	STME	Stellaria media	30.0	-
*	SYMI	Synthyris missurica	15.0	15.5
*	TAOF	Taraxacum officionale	40.0	8.6
	THMO	Thermopsis montana	10.0	3.4
*	THOC	Thalictrum occidentale	50.0	70.7
*	TITR	Tiarella trifoliata	60.0	31.0
*	TRDU	Tragopogon dubius	35.0	3.4
	TRIFO	Trifolium spp.	5.0	-
	TRPR	Trifolium pratense	5.0	-
*	TRRE	Trifolium repens	15.0	20.7
	URDI	Urtica dioica	10.0	1.7
	VASI	Valeriana sitchensis	5.0	5.2
	VECA	Veratrum californicum	10.0	1.7
	VETH	Verbascum thapsus	5.0	-
*	VIOLA	Viola spp.	40.0	22.4
*	VIAD	Viola adunca	65.0	22.4
*	VIOR2	Viola orbiculata	100.0	87.9
	ANNUAL GRAMINOIDS			
	BRTE	Bromus tectorum	-	1.7
	ANNUAL FORBS			
	COPA	Collinsia parviflora	5.0	8.6
	COTI	Collomia tinctoria	-	1.7
	CRAF	Crypthantha affinis	5.0	3.4
	EPPA	Epilobium paniculatum	20.0	1.7
*	GAAP	Galium aparine	30.0	15.5
	GABO	Galium borale	30.0	0.3
	LASE	Lactuca serriola	30.0	-

Table 2. continued

	Species Symbol	Scientific Name	Constancy (%) Damaged n=20	Undamaged n=58
	MADIA	Madia spp.	-	1.7
	MIGR	Microsteris gracilis	-	3.4
*	MOPE	Montia perfoliata	50.0	12.1
*	MOSI	Montia sibirica	75.0	10.3
	NAVAR	Navarretia spp.	-	1.7
	POLYG	Polygonum spp.	-	1.7
	PODO	Polygonum douglasii	5.0	-
	POHE1	Polygonum heterosepalum	-	1.7

1/ Penstemon confertus is considered a perennial forb but was inadvertently listed as a shrub

* species which were selected for probability of occurrence modeling

Table 3. A comparison of selected overstory characteristics among severely, moderately, lightly, and undamaged stands.

Overstory Characteristic	Severely damaged n=11		Moderately damaged n=3		Lightly damaged n=3		Undamaged n=10	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Live tree density/ha[1/]	373	80-1280	480	320-667	853	213-1787	1440	347-4241
Dead tree density/ha[1/]	933	267-2027	320	27-533	8	0-27	0	----
Live basal area (m^2/ha)	10.13	1.33-32.0	42.41	2.13-87.21	72.54	45.87-119.21	50.67	30.67-90.94
Dead basal area (m^2/ha)[2/]	42.67	3.47-82.68	18.94	11.47-29.87	0.27	0-0.80	0	----
Average tree height (m)	13.7	4.8-25.2	17.5	4.5-24.4	20.0	9.0-31.0	15.8	3.8-32.4
Live crown ratio (%)	35	19-44	43	31-58	50	33-61	46	29-64
Percentage crown cover[3/]	68	54-87	71	56-98	82	70-93	84	64-99

1/ trees > 1.4 m tall.

2/ Mortality assumed a result of Douglas-fir tussock moth defoliation.

3/ Determined with a spherical densiometer.

Table 4 . Average numbers of understory species per macroplot sample ($375m^2$) among severely, moderately, lightly and undamaged stands.

	Severely damaged n=11	Moderately damaged n=6	Lightly damaged n=3	Undamaged n=10
Understory Trees	1	2	1	2
Highly Preferred Shrubs	1	1	0	1
Moderately Preferred Shrubs	3	3	3	4
Least Preferred Shrubs	3	1	2	2
Perennial Gramineae	3	2	1	1
Cyperaceae + Juncaceae	1	1	1	1
Perennial Forbs	22	17	19	15
Annual Graminoids	0	0	0	0
Annual Forbs	2	2	0	0
TOTAL SPECIES	$\bar{x}$ 36 $s_{\bar{x}}$ 0.65	$\bar{x}$ 29 $s_{\bar{x}}$ 5	$\bar{x}$ 27 $s_{\bar{x}}$ 5	$\bar{x}$ 26 $s_{\bar{x}}$ 3

Table 5 . Summed coverage values by growth form categories of species encountered among severely, moderately, lightly and undamaged stands.

Vegetation Category	Severely damaged		Moderately damaged		Lightly damaged		Undamaged	
	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$
UNDERSTORY TREES	1.7	1.5	2.2	1.4	0.5	0.2	4.9	2.2
TOTAL SHRUB	36.3	9.7	20.4	7.0	13.3	6.5	24.7	7.7
Highly preferred	1.5	0.5	0.3	0.2	-	-	5.0	4.1
Moderately preferred	10.7	5.0	10.3	4.9	11.5	6.5	9.3	2.6
Least preferred	24.7	5.8	9.8	4.2	1.8	0.3	10.4	5.0
TOTAL HERBACEOUS	140.5	15.8	94.1	22.4	82.9	32.9	51.8	13.2
Total Graminoids	25.1	7.3	14.4	6.1	2.8	1.4	3.4	1.6
Gramineae	21.7	6.0	12.3	5.1	2.7	1.3	2.4	1.1
Cyperaceae + Juncaceae	3.3	1.3	2.1	1.2	0.1	0.1	1.0	0.8
Perennial Forb	88.3	9.0	76.6	19.5	80.1	31.6	47.8	12.4
Annuals	27.0	7.8	3.1	1.6	-	-	0.5	0.4
TOTAL UNDERSTORY COVER	178.6	13.1	116.7	25.8	96.7	39.4	81.4	19.2

Table 6. A comparison of understory composition and structure among severely, moderately, lightly, and undamaged stands.

Species	Severely Damaged (n=11)					Moderately Damaged (n=6)					Lightly Damaged (n=3)					Undamaged (n=10)				
	Constancy	Canopy Coverage		Frequency		Constancy	Canopy Coverage		Frequency		Constancy	Canopy Coverage		Frequency		Constancy	Canopy Coverage		Frequency	
		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$
UNDERSTORY TREES																				
Abies grandis	46	3.5	3.3	6.9	2.8	67	2.9	1.9	9.4	1.2	100	0.3	0.1	10.0	2.5	100	4.3	1.9	33.3	8.2
Larix occidentalis	27	0.1	0	2.5	0	17	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Picea engelmannii	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	40	0.9	0.4	9.4	4.3
Pseudotsuga menziesii glauca	9	-	-	-	-	50	0.3	0.2	4.2	0.8	-	-	-	-	-	40	0.3	0.1	5.8	0.8
SHRUBS																				
Acer glabrum	73	2.7	1.5	5.5	1.9	67	0.8	0.7	-	-	100	0.3	0.2	2.5	0	40	1.0	0.9	2.5	0
Alnus spp.	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alnus tenuifolia	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amelanchier alnifolia	63.6	1.9	0.9	-	-	67	0.5	0.3	2.5	0	33	-	-	-	-	60	0.4	0.2	-	-
Berberis repens	9	-	-	-	-	33	-	-	-	-	33	-	-	-	-	40	0.2	0.2	2.5	0
Ceanothus sanguineus	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chimaphila menziesii	-	-	-	-	-	33	-	-	-	-	100	1.0	0.2	27.5	7.6	40	0.3	0.1	9.4	2.1
Chimaphila umbellata	46	2.5	1.9	19.4	13.6	50	4.6	1.2	23.8	3.8	67	0.4	0	3.8	1.3	90	2.3	1.3	16.4	8.0
Holodiscus discolor	55	8.5	4.7	15.0	10.0	17	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Linnaea borealis	82	21.8	5.8	51.6	12.0	33	14.6	8.9	67.5	27.5	-	-	-	-	-	60	17.2	6.5	57.0	15.3
Lonicera ciliosa	46	1.1	0.6	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lonicera utahensis	9	-	-	-	-	17	-	-	-	-	100	-	-	-	-	50	0.3	0.1	2.5	0
Pachistima myrsinites	9	-	-	-	-	33	0.4	0.4	-	-	-	-	-	-	-	50	-	-	-	-
Penstemon confertus [1/]	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	-	-	-	-	-
Philadelphus lewisii	18	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ribes lacustre	73	2.9	1.0	23.3	5.2	33	1.0	0.9	-	-	100	0.2	0.2	-	-	40	-	-	-	-
Ribes viscosissimum	9	-	-	-	-	33	1.7	1.4	2.5	0	33	-	-	-	-	10	-	-	-	-
Rosa spp.	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rosa gymnocarpa	73	2.9	2.0	9.2	4.2	67	6.0	1.4	9.4	2.6	67	-	-	-	-	80	2.1	0.6	9.4	2.4
Rubus spp.	27	2.5	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rubus idaeus	18	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rubus parviflorus	73	4.1	1.4	12.0	1.8	33	-	-	-	-	67	-	-	-	-	10	-	-	-	-
Salix spp.	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sambucus cerulea	27	4.2	0.1	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sambucus racemosa	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sorbus scopulina	27	-	-	-	-	-	-	-	-	-	67	-	-	-	-	20	1.0	0.9	-	-
Spirea betulifolia lucida	36	2.9	2.5	-	-	67	3.0	0.7	5.0	0	33	-	-	-	-	50	1.6	1.0	13.8	6.3
Symphoricarpos albus	64	2.8	0.6	5.0	0.8	67	2.8	1.4	12.5	0	-	-	-	-	-	60	0.9	0.5	7.5	3.5
Taxus brevifolia	55	0.2	0.1	6.0	1.0	17	-	-	-	-	-	-	-	-	-	20	24.4	17.2	6.3	3.8
Vaccinium membranaceum	27	-	-	-	-	33	-	-	-	-	100	14.0	8.4	13.8	8.8	90	6.6	2.2	19.4	6.1

Table 6. Continued

Species	Severely Damaged (n=11) Constancy	Canopy Coverage $\bar{x}$	Canopy Coverage $s_{\bar{x}}$	Frequency $\bar{x}$	Frequency $s_{\bar{x}}$	Moderately Damaged (n=6) Constancy	Canopy Coverage $\bar{x}$	Canopy Coverage $s_{\bar{x}}$	Frequency $\bar{x}$	Frequency $s_{\bar{x}}$	Lightly Damaged (n=3) Constancy	Canopy Coverage $\bar{x}$	Canopy Coverage $s_{\bar{x}}$	Frequency $\bar{x}$	Frequency $s_{\bar{x}}$	Undamaged (n=10) Constancy	Canopy Coverage $\bar{x}$	Canopy Coverage s_x	Frequency $\bar{x}$	Frequency s_x
PERENNIAL GRAMINOIDS																				
Agropyron spicatum	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bromus vulgaris	100	5.1	1.5	12.5	2.2	100	5.3	2.1	24.5	7.7	67	3.6	0.2	20.0	10.0	50	0.2	0.2	-	-
Carex spp.	72	2.6	0.7	8.2	2.3	67	3.0	1.7	11.7	5.1	33	-	-	-	-	80	1.3	1.1	8.8	4.3
Carex geyerii	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calamagrostis rubescens	18	2.1	0.5	3.8	1.3	33	10.6	9.1	25.0	15.0	33	-	-	-	-	20	1.2	1.2	6.3	3.8
Festuca occidentalis	91	16.1	6	36.4	9.7	83	6.2	3.2	21.3	4.1	33	-	-	-	-	60	3.5	1.6	22.1	8.5
Festuca subulata	36	3.7	3.1	12.5	7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Luzula carpestris	18	1.1	0.4	-	-	-	-	-	-	-	-	-	-	-	-	20	-	-	-	-
Melica subulata	9	-	-	-	-	33	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Poa pratensis	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sitanion hystrix	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trisetum canescens	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	30	-	-	-	-
PERENNIAL FORBS																				
Achillea millefolium lanulosa	27	1.0	0.9	-	-	33	-	-	-	-	33	-	-	-	-	20	0.1	0	2.5	0
Actaea rubra	-	-	-	-	-	-	-	-	-	-	100	2.6	1.0	-	-	20	-	-	-	-
Adenocaulon bicolor	91	3.1	1.2	13.9	3.9	67	6.8	3.8	26.7	5.8	67	-	-	-	-	40	0.2	0.1	3.3	0.8
Agoseris spp.	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anemone piperi	100	1.5	0.4	21.3	5.3	83	6.2	1.8	50.0	9.5	100	8.9	1.7	56.7	8.7	100	2.9	0.7	38.5	7.6
Arnica cordifolia	91	2.2	1.1	14.6	6.9	100	9.7	3.4	37.0	8.3	100	42.5	0.3	86.3	6.3	100	16.4	4.6	48.6	10.8
Arenaria macrophylla	91	7.1	1.4	44.0	5.5	100	5.3	1.7	47.5	13.3	100	1.9	0.5	15.5	3.3	60	4.2	2.0	38.8	10.5
Astragalus canadensis mortonii	36	2.3	1.0	-	-	33	-	-	-	-	-	-	-	-	-	30	0.2	0.1	-	-
Aquilegia formosa	27	-	-	-	-	17	-	-	-	-	33	-	-	-	-	10	-	-	-	-
Calypso bulbosa	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	40	0.1	0	2.5	0
Cerastium vulgatum	36	3.0	1.8	13.3	1.7	33	0.7	0.3	-	-	-	-	-	-	-	-	-	-	-	-
Circaea alpina	46	1.3	0.3	8.3	1.7	50	0.2	0.1	3.3	0.8	33	-	-	-	-	-	-	-	-	-
Cirsium arvense	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cirsium vulgare	82	5.3	1.8	15.3	4.6	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clintonia uniflora	55	12.2	5.4	27.9	10.2	33	-	-	-	-	67	-	-	-	-	50	9.0	2.9	40.0	4.7
Coralloriza maculata	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	30	-	-	-	-
Cystopteris fragilis	46	1.1	0.2	6.9	1.2	33	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Cystopteris montana	9	-	-	-	-	17	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Disporum trachycarpum	64	4.0	2.2	6.5	1.5	50	3.3	1.2	11.3	1.3	100	3.9	3.4	-	-	40	0.2	0.2	2.5	0
Epilobium angustifolium	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epilobium glaberrimum	55	6.4	2.3	31.7	6.4	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epilobium watsonii	27	3.8	2.2	21.7	5.8	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Erythronium spp.	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragaria vesca	91	3.4	1.5	18.3	6.6	67	4.2	1.6	20.6	7.2	67	4.8	2.9	11.3	6.3	60	4.8	2.0	26.5	7.6
Galium boreale	64	0.9	0.2	18.9	5.1	17	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Galium triflorum	91	13.4	2.3	45.5	4.6	83	12.4	4.9	52.0	10.2	100	5.0	2.1	29.2	11.7	60	2.7	1.0	24.2	6.2

Table 6. Continued

Species	Severely Damaged (n=11)					Moderately Damaged (n=6)					Lightly Damaged (n=3)					Undamaged (n=10)				
	Constancy	Canopy Coverage		Frequency		Constancy	Canopy Coverage		Frequency		Constancy	Canopy Coverage		Frequency		Constancy	Canopy Coverage		Frequency	
		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$
Goodyera oblongifolia	45	0.5	0.3	8.3	3.3	50	0.1	0	3.8	1.3	100	0.3	0.1	6.7	3.0	80	0.3	0.1	4.3	1.1
Habenaria unalascensis	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Hieracium spp.	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hieracium albiflorum	100	2.2	0.5	21.4	4.0	100	4.7	1.7	31.5	10.5	100	2.4	0.9	20.0	5.0	70	1.6	0.7	21.1	6.8
Hydrophyllum capitatum	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrophyllum fendleri	27	0.8	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lathyrus spp.	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Listera caurina	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	30	0.8	0.6	12.5	5.0
Lithospermum ruderale	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lupinus caudatus	55	2.8	1.0	12.5	4.7	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mertensia paniculata	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	-	-	-	-	-
Mitella stauropetala	73	8.7	3.2	39.6	10.7	50	7.9	3.5	33.3	15.4	100	3.1	1.3	22.5	10.1	50	2.0	1.1	24.0	6.2
Osmorhiza chilensis	100	11.9	3.5	31.8	6.9	100	7.8	2.9	39.6	9.5	100	2.9	0.6	26.7	8.2	90	2.0	0.4	23.9	5.5
Penstemon spp.	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pedicularis racemosa	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	10	-	-	-	-
Phacelia hastata	18	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potentilla spp.	-	-	-	-	-	17	-	-	-	-	33	-	-	-	-	10	-	-	-	-
Polystichum munitum	36	5.1	2.5	3.8	1.3	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polemonium pulcherrimum	9	-	-	-	-	17	-	-	-	-	100	0.6	0.3	2.5	0.0	30	-	-	-	-
Pteridium aquilinum	9	-	-	-	-	17	-	-	-	-	33	-	-	-	-	10	-	-	-	-
Pyrola asarifolia	18	1.3	0.9	-	-	-	-	-	-	-	-	-	-	-	-	40	1.0	0.2	7.5	2.5
Pyrola chlorantha	9	-	-	-	-	33	-	-	-	-	-	-	-	-	-	20	-	-	-	-
Pyrola picta	-	-	-	-	-	-	-	-	-	-	67	-	-	-	-	20	-	-	-	-
Pyrola secunda	63	0.2	0.1	4.4	1.2	17	-	-	-	-	100	0.9	0.4	7.5	0	70	1.6	0.2	23.0	1.8
Ranunculus spp.	9	-	-	-	-	17	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Ranunculus uncinatus	55	0.7	0.5	6.7	1.7	33	0.5	0.4	5.0	2.5	33	-	-	-	-	20	1.4	0.7	13.8	3.8
Rumex acetosella	18	0.2	0.1	-	-	33	0.4	0	-	-	-	-	-	-	-	-	-	-	-	-
Rudbeckia occidentalis	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Smilacina racemosa	18	-	-	-	-	83	0.5	0.4	-	-	-	-	-	-	-	30	1.4	0.9	6.3	1.3
Smilacina stellata	55	3.0	1.2	10.6	3.7	50	7.2	6.9	27.5	22.5	67	-	-	-	-	70	3.3	2.1	19.0	6.8
Stellaria media	45	4.8	1.7	12.0	2.5	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Synthyris missurica	18	0.4	0.4	-	-	-	-	-	-	-	33	-	-	-	-	10	-	-	-	-
Taraxacum officionale	55	1.5	1.2	6.3	1.3	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thermopsis montana	9	-	-	-	-	17	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Thalictrum occidentale	18	6.4	3.4	20.0	2.5	83	5.8	2.1	19.0	9.4	100	5.8	3.5	25.8	11.8	70	4.6	1.4	24.6	5.8
Tiarella trifoliata	64	9.5	3.7	33.9	8.3	33	2.7	2.3	8.8	3.8	100	2.4	2.0	15.0	12.5	-	3.1	1.4	21.0	5.2
Tragopogon dubius	55	1.4	0.3	5.0	2.5	17	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Trifolium spp.	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium repens	9	-	-	-	-	33	8.3	7.9	31.3	26.3	-	-	-	-	-	-	-	-	-	-
Urtica dioica	-	-	-	-	-	17	-	-	-	-	33	-	-	-	-	-	-	-	-	-
Valeriana sitchensis	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	-	-	-	-	-

Table 6. Continued

Species	Severely Damaged (n=11)					Moderately Damaged (n=6)					Lightly Damaged (n=3)					Undamaged (n=10)				
	Constancy	Canopy Coverage		Frequency		Constancy	Canopy Coverage		Frequency		Constancy	Canopy Coverage		Frequency		Constancy	Canopy Coverage		Frequency	
		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$		$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$
Veratrum californicum	9	-	-	-	-	-	-	-	-	-	33	-	-	-	-	10	-	-	-	-
Verbascum thapsus	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Viola spp.	18	1.9	1.5	15.0	10.0	50	3.0	1.7	20.0	7.2	100	1.5	1.1	14.2	7.3	10	-	-	-	-
Viola adunca	64	0.7	0.4	10.0	4.4	67	1.4	1.3	13.8	10.4	67	0.1	0	2.5	0	20	0.4	0.4	8.8	6.3
Viola orbiculata	100	2.7	0.7	29.5	6.5	100	2.7	1.2	25.0	9.0	100	0.8	0.3	17.5	3.8	90	3.4	1.1	42.2	9.0
ANNUALS																				
Collinsia parviflora	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Cryptantha affinis	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epilobium paniculatum	27	1.7	1.0	5.8	1.7	17	1.8	1.4	-	-	-	-	-	-	-	-	-	-	-	-
Galium aparine	36	10.2	2.6	-	-	33	-	-	-	-	-	-	-	-	-	20	0.4	0.4	6.3	1.3
Galium aparine echinospermum	27	18.2	8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lactuca serriola	46	5.0	1.2	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Montia perfoliata	63	10.5	5.2	-	-	50	1.7	1.6	18.3	14.6	-	-	-	-	-	-	-	-	-	-
Montia sibirica	82	12.1	2.5	-	-	-	2.4	1.0	-	-	67	-	-	-	-	10	-	-	-	-
Polygonum douglasii	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] Penstemon confertus is considered a perennial forb but was inadvertently listed as a shrub

Table 7. A comparison of understory composition and structure for severely damaged stands first measured in 1975 and remeasured in 1977. The stands are representative of the Abies grandis-Pachistima habitat type in the northern Blue Mountains, southeastern Washington. Only species with cover and/or frequency values are shown in the table.

Selected Species	1975					1977				
		Canopy Coverage		Frequency			Canopy Coverage		Frequency	
	Constancy	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	Constancy	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$
SHRUBS										
Acer glabrum	100	2.1	1.4	2.5	0	67	0.8	0.7	5.0	0
Chimaphila umbellata	100	0.6	0.5	6.3	3.8	-	-	-	-	-
Ribes lacustre	100	1.4	0.8	17.5	15.0	66	7.0	0.4	30.0	10.0
Rosa gymnocarpa	100	0.4	0	-	-	-	-	-	-	-
Rubus spp.	67	-	-	-	-	67	2.5	2.5	-	-
Rubus parviflorus	67	-	-	-	-	67	1.3	0.5	-	-
Symphoricarpos albus	67	1.2	0.4	-	-	67	4.4	1.2	5.0	0
PERENNIAL GRAMINOIDS										
Bromus vulgaris	100	5.8	4.4	11.3	8.8	100	8.3	3.4	16.7	4.4
Carex spp.	67	1.4	1.0	5.0	2.5	33	-	-	-	-
Festuca occidentalis	100	1.5	0.6	5.0	0	100	10.0	3.0	28.3	6.0
PERENNIAL FORBS										
Adenocaulon bicolor	100	2.4	0.9	6.3	3.8	67	0.3	0	12.5	2.5
Anemone piperi	100	1.1	0.2	8.8	1.3	100	1.2	0.3	15.0	2.9
Arnica cordifolia	100	1.3	1.2	3.8	1.3	67	0.1	0	-	-
Arenaria macrophylla	100	6.4	1.0	31.7	2.2	100	4.2	1.3	45.0	8.7
Cerastium vulgatum	-	-	-	-	-	67	1.2	0.4	12.5	2.5
Circaea alpina	67	4.0	2.9	-	-	33	T[1/]	-	21.7	11.7
Cirsium vulgare	100	T	-	10.8	3.3	100	9.2	4.4	-	-
Clintonia uniflora	67	8.0	5.0	20.0	7.5	67	25.8	10.5	52.5	22.5

Table 7. Continued

Selected Species	1975 Constancy	1975 Canopy Coverage $\bar{x}$	1975 Canopy Coverage $s_{\bar{x}}$	1975 Frequency $\bar{x}$	1975 Frequency $s_{\bar{x}}$	1977 Constancy	1977 Canopy Coverage $\bar{x}$	1977 Canopy Coverage $s_{\bar{x}}$	1977 Frequency $\bar{x}$	1977 Frequency $s_{\bar{x}}$
Disporum trachycarpum	100	0.4	0.4	3.8	1.3	33	-	-	-	-
Epilobium watsonii	100	3.8	2.2	21.7	5.8	100	3.1	0.6	23.3	6.0
Fragaria vesca	100	0.6	0.2	4.2	0.8	100	2.9	2.8	20.0	15.0
Galium boreale	-	-	-	-	-	100	0.7	0.2	18.3	10.9
Galium triflorum	100	10.4	1.5	31.7	7.3	100	11.0	1.9	55.0	2.9
Goodyera oblongifolia	100	0.8	0.4	10.0	5.0	67	0.1	0	-	-
Hieracium albiflorum	100	2.9	0.7	22.5	8.0	100	1.4	0.6	18.3	3.3
Linnaea borealis	100	20.1	9.2	40.8	19.1	100	21.5	11.2	50.0	24.7
Lupinus caudatus	33	-	-	-	-	67	0.8	0	-	-
Mitella stauropetala	67	3.8	2.0	21.3	8.8	67	9.7	7.6	32.5	12.5
Osmorhiza chilensis	100	16.8	5.6	25.8	9.6	100	13.2	5.1	43.3	6.0
Polystichum munitum	67	1.8	0.2	-	-	33	-	-	-	-
Pyrola secunda	100	0.3	0.2	5.0	2.5	33	-	-	-	-
Ranunculus uncinatus	100	0.2	0.2	-	-	33	-	-	-	-
Smilacina stellata	67	0.6	0.5	5.0	2.5	33	-	-	-	-
Tiraella trifoliata	100	6.7	4.2	32.5	14.4	67	17.6	10.7	45.0	15.0
Tragopogon dubius	100	1.0	0.1	-	-	-	-	-	-	-
Viola orbiculata	100	3.6	2.3	31.7	15.9	100	2.1	0.7	31.7	13.6
ANNUALS										
Epilobium paniculatum	100	1.7	1.0	5.8	1.7	-	-	-	-	-
Galium aparine	33	-	-	-	-	100	18.2	8.0	33.3	14.2
Lactuca serriola	100	4.6	2.1	20.8	4.6	33	-	-	-	-

Table 7. Continued

Selected Species	1975					1977				
		Canopy Coverage		Frequency			Canopy Coverage		Frequency	
	Constancy	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	Constancy	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$
Montia perfoliata	67	-	-	-	-	100	4.1	0.5	16.7	3.3
Montia sibirica	100	10.9	6.9	29.2	12.9	100	16.3	3.0	56.7	3.3

1/ T = values less than 0.1%

Table 8. A comparison of understory current year production among severe, moderate, light, and undamaged stands.

Vegetation Component	Current Year Production (air-dry grams/375m^2)							
	Severely damaged n=8		Moderately damaged n=3		Lightly damaged n=3		Undamaged n=10	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Total Production	34808.7	12953.5-50216.0	10296.9	420.6-23951.4	8828.5	2187.0-17012.0	6860.6	325.9-16749.2
Total Shrub	9840.4	2176.4-18473.5	1776.9	31.5-3217.4	1153.1	136.7-3070.2	2703.2	231.3-8674.2
Highly Preferred	347.8	0.0-1408.9	10.5	0.0-31.5	0.0	0.0-0.0	131.4	0.0-1188.1
Moderately Preferred	3125.8	224.3-10325.0	1282.7	0.0-2239.5	1072.4	31.5-3038.6	1380.5	0.0-4784.0
Least Preferred	6279.2	0.0-15420.9	483.6	0.0-977.8	80.6	31.5-105.1	1191.3	0.0-5057.3
Total Herbage	24968.3	5530.5-41804.6	8520.0	389.0-20734.1	7675.4	2050.3-13941.9	4157.3	94.6-11302.8
Total Graminoids	5360.1	63.1-12589.0	1924.1	105.1-5225.6	226.4	0.0-588.8	234.5	0.0-893.7
Gramineae	4473.4	63.1-10240.9	1850.5	105.1-5078.4	252.3	0.0-588.8	202.9	0.0-778.1
Cyperaceae + Juncaceae	886.7	0.0-2691.6	73.6	0.0-147.2	14.0	0.0-42.1	31.6	0.0-115.1
Perennial Forbs	19293.6	5467.4-32026.4	6571.4	283.9-15434.9	7409.0	2050.3-13353.1	3922.9	94.6-11302.8
Annuals	314.6	0.0-1233.7	24.5	0.0-73.6	0.0	-----	0.0	-----

Table 9. Canopy coverage and rooted frequency linear multiple regression models for selected understory species. Refer to Table 10 for definition of independent variables.

Species by Constancy Class	Species Characteristic[1]	Regression coefficients for independent variables included in the linear regression models										R^2	Prob. > F[2]
		Intercept	Cosaspect	Sinaspect	Tan Slope	Density	BAR	AVEBLC	AVECRN	Sum DIA	DBHTGF		
>80% Constancy													
Chimaphila umbellata	CV	8.5637	-2.3141	1.6370	1.2415	0.0760	-2.9332	0	0	-1.0240	0	0.3289	0.0412
	FR	40.8395	-3.3040	8.7890	0.5116	0.3708	-10.4207	0	0	-4.6806	0	0.3767	0.0164
Vaccinium membranaceum	CV	32.8911	0.5692	5.6560	8.7462	0.0678	-18.9736	-0.7913	0	-1.7093	0	0.3874	0.0154
	FR	62.8783	-7.7128	4.9791	6.8883	0.1960	-20.1077	0	0	-4.3897	-0.3939	0.4497	0.0036
Anemone piperi	CV	10.5658	2.1649	-0.7169	0.7496	-0.0508	-9.3506	-1.0572	0.3528	0.6566	0.1155	0.3238	0.0228
	FR	65.0555	8.0139	-6.0421	1.3419	-0.0674	-31.7951	-3.4556	3.5312	0	0	0.2925	0.0148
Arnica cordifolia	CV	39.0046	10.2771	-4.4849	-2.6461	0	-15.6784	-1.9226	0	-2.0924	0.7330	0.3148	0.0249
	FR	97.2238	2.4582	-3.3181	17.4677	0	-34.3190	-4.1692	0	-4.0208	0.9039	0.3131	0.0259
Goodyera oblongifolia	CV	-0.0778	-1.4241	0.0310	1.1362	0	1.1455	0	0.0563	0	-0.0243	0.3487	0.0461
	FR	1.7696	-9.6834	2.4537	3.5168	0	9.7903	0.4824	0	0	-0.2140	0.3001	0.0992
Hieracium albiflorum	CV	3.4595	0.5802	0.0623	-1.7031	0	-1.0995	0	0.0625	-0.1698	0	0.2691	0.0722
	FR	19.9360	4.0356	5.2381	-15.0184	0.0316	0	0	2.7184	-1.4391	-0.4646	0.36196	0.0222
Osmorhiza chilensis	CV	7.8018	0.7019	0.7991	-3.7603	-0.0280	-4.1595	-0.4449	0	0	0.1190	0.4138	0.0070
	FR	34.9219	-1.3629	0.2861	-19.5573	0	-8.9652	-1.1988	3.0466	-1.8393	0	0.4327	0.0044
Viola orbiculata	CV	8.7934	1.3682	1.1879	-2.9073	0	-4.4779	-0.4087	0	.0	0.0875	0.1368	0.3732
	FR	59.0101	8.8038	12.5376	-22.9922	0.2483	0	0	1.9892	-4.5436	0	0.1872	0.1676
70-80% Constancy													
Rosa gymnocarpa	CV	6.0079	1.9157	-1.3061	7.2815	-3.8576	0	0	0	-0.5544	0	0.3132	0.1023
	FR	1.4314	3.2189	-0.9085	6.4255	0	-5.8540	0	0	0	0.1877	0.2317	0.2657
Arenaria macrophylla	CV	-0.0757	-2.9313	-1.4242	5.4596	0.0195	0	0	0.2877	-0.2617	0.0731	0.4517	0.0044
	FR	-0.8330	-12.8229	-15.2535	22.5169	0	17.9958	0	3.9261	0	-0.3488	0.4143	0.0088
Pyrola secunda	CV	2.6818	-1.9494	-2.1439	1.1847	0	0	-0.1001	0	-0.2269	0.0616	0.3863	0.0163
	FR	20.0430	-14.9333	-9.7322	23.7831	0.0786	0	0	1.7957	-3.1804	0	0.4319	0.0062
Thalictrum occidentalis	CV	28.7550	0.1665	-2.2153	-4.1500	-0.1773	-9.0146	-1.7263	0	0	0.1195	0.5159	0.0060
	FR	72.2418	3.7724	2.9240	-7.9858	-0.4798	-13.4249	-3.6026	1.4744	0	-0.3339	0.5560	0.0055
60-70% Constancy													
Amelanchier alnifolia	CV	-1.1784	-0.0717	-0.2881	2.0143	0.0786	0	0.7422	0	-1.1021	0	05.129	0.3199
	FR	-4.9978	-2.3896	2.7941	-4.2628	0.1368	0	1.6722	-0.7820	-1.2610	0.1418	0.8771	0.0278
Linnaea borealis	CV	12.8656	-9.5986	-6.5842	-1.2374	0.4880	26.3351	2.9900	2.0613	-6.4276	-0.8214	0.5741	0.0043
	FR	21.2084	-21.7718	-33.4875	17.2359	0.6499	65.7862	5.6951	4.6267	-10.7623	-1.7675	0.3520	0.1991
Carex spp.	CV	4.8759	-2.2432	4.8016	1.3834	-0.0163	0	0	0	0	-0.1051	0.2667	0.1165
	FR	19.8624	-3.1162	9.3675	-4.9296	0	-7.7965	0	0	-0.7463	0	0.2518	0.1431
Fragaria vesca	CV	10.7573	-4.6574	-0.5970	-2.1698	0.0362	0	0	0	-1.1144	-0.0642	0.5356	0.0056
	FR	47.7783	-14.1807	-5.1925	-10.0288	0.2044	0	-0.7797	1.6864	-4.4095	-0.5422	0.7031	0.0006
Galium triflorum	CV	8.9129	0.8613	-1.4424	-2.5767	0	0	-0.3780	0	-0.6067	0.1232	0.4554	0.0075
	FR	52.7430	4.8903	-2.4556	-8.1314	0.0223	0	-0.8278	0	-4.4111	0.4658	0.5004	0.0064
Mitella stauropetala	CV	1.9613	-4.3196	-1.6214	8.9838	0.0165	0.9980	0.2544	-0.1738	-0.6257	0	-0.5422	0.0042
	FR	13.1820	-25.5040	-12.8312	56.0347	0.2904	15.1325	2.8111	0	-6.1355	-0.4105	0.5989	0.0010
50-60% Constancy													
Chimaphila menziesii	CV	0.3736	-0.1845	0.3259	-0.1155	0	0	0	0.0171	0	-0.0079	0.5848	0.0094
	FR	8.8425	-1.8075	5.8904	-4.6543	0	-5.1338	-0.3486	0.6611	0	0	0.4488	0.1237
Ribes lacustre	CV	3.2792	-0.2550	-0.8118	4.6904	-0.1089	2.8260	0.5048	-0.3369	0.0198	-0.1413	1.0000	0.0001
	FR	10.1818	8.0615	-6.1650	-3.9084	-0.4435	-3.6592	-1.0316	-0.5193	4.1006	-0.2170	1.0000	0.0001
Spirea betulifolia	CV	2.9697	3.9761	6.9298	1.5566	0.0840	0	1.6083	1.0310	-1.8200	-0.4773	0.7127	0.0032
	FR	6.6692	15.4596	18.2710	-7.7869	0.3499	0	5.4739	2.5644	-6.0693	-1.0693	0.7146	0.0030
Bromus vulgaris	CV	0.8422	-0.6301	-0.4519	1.1637	0	1.2025	0.0889	-0.1177	-0.1469	0	0.4424	0.3050
	FR	5.9384	-3.7353	-1.2869	1.6294	0	6.5056	0.3975	-0.5027	-0.7408	0	0.5248	0.1582
Festuca occidentalis	CV	8.4763	-3.1359	5.4377	-1.1867	0.0476	2.8795	0	0	-0.7598	-0.1750	0.5466	0.0076
	FR	20.1607	-17.6517	14.2503	1.6191	0.5516	30.2672	4.6788	0	-8.1877	-1.0338	0.5415	0.0179
Smilacina racemosa	CV	17.9355	-4.6522	1.5603	-1.4755	-0.1883	0	0	0	-0.4133	-0.1813	0.4082	0.1545
	FR	32.1395	7.5770	1.3682	-40.3093	0	0	-1.0948	3.4231	0	-0.7295	0.3313	0.3040

Table 9 . Continued

Species by Constancy Class	Species Characteristic[1]	Regression coefficients for independent variables included in the linear regression models										R^2	Prob. > F[2]
		Intercept	Cosaspect	Sinaspect	Tan Slope	Density	BAR	AVEBLC	AVECRN	Sum DIA	DBHTGF		
40-50% Constancy													
Acer glabrum	CV	83.0089	27.7319	-15.8675	7.7393	0.1166	0	3.2854	1.2713	-19.6677	-0.2147	1.0000	0.0001
	FR	458.0293	202.6274	-125.9811	-149.2399	0	-137.6013	0.9993	3.7701	-71.3555	2.7607	1.0000	0.0001
Berberis repens	CV	-1.6771	4.5736	5.5489	-4.8515	0.0119	0	0.1437	0.3807	0	0	1.0000	0.0001
	FR	7.8980	37.7048	13.3734	-36.7587	0	-7.0441	0	0	0.0722	0.6790	1.0000	0.0001
Clintonia uniflora	CV	20.8332	-8.2031	1.5917	-4.4319	0	0	0	0	-1.7231	0	0.4902	0.0094
	FR	62.8586	-19.5083	1.5527	-21.8916	0	0	0	0	-4.1400	0	0.3078	0.1191
Disporum trachycarpum	CV	-6.2109	-7.7604	-4.8398	1.9100	0	22.0921	0	2.2940	0	-0.7447	0.6239	0.2039
	FR	-10.2169	-14.0060	-8.8647	9.1145	0	43.0707	0	4.2284	0	-1.4172	0.5499	0.3247
30-40% Constancy													
Lonicera utahensis	CV	0.8626	-0.8357	-1.3425	1.4607	0	0	0	-0.1163	0	0	0.6367	0.0265
	FR												
Symphoricarpos albus	CV												
	FR	2.8435	9.1462	18.4745	24.2984	0	0	0	0	0	0	0.3195	0.4121
Adenocaulon bicolor	CV	-3.6343	8.2561	14.0947	-12.7986	0	0	0.3261	1.0270	-0.1900	-0.0206	0.8006	0.0037
	FR	-20.0740	25.8947	48.6875	-43.8003	0	13.2685	1.2650	3.8739	0	-0.3117	0.8330	0.0015
Calypso bulbosa	CV	0.1440	-0.5258	-0.1818	0.7266	0	-0.1786	0	0	0	0	0.4803	0.0995
	FR	3.7444	-7.3037	-1.8897	10.0412	0	0	0.8969	-0.8190	-0.5513	0	0.4678	0.3402
Polemonium pulcherrimum	CV	-25.1682	4.6161	22.4320	-33.2213	-0.0747	5.0315	-2.2334	-1.5310	7.3725	0.8030	1.0000	0.0001
	FR	-46.5167	5.2703	66.2913	-48.1590	-0.2481	34.7487	-3.0522	-3.1303	13.6441	0.9181	1.0000	0.0001
Tiarella trifoliata	CV	4.7733	-3.3651	0.9285	-6.7421	0	0	0	0	0	0	0.4581	0.0935
	FR	33.8830	-15.8531	-3.2981	-51.4201	0	0	0	0	0	0	0.5315	0.0477

[1]CV = canopy coverage (%), FR = rooted frequency (%)

[2]the level of significance for the entire model

Table 10. Definition of independent variables used in the selected canopy coverage and rooted frequency models.

Variable	Definition
cosaspect	Cos(aspect) x tan(slope); aspect in degrees, tan(slope) = slope %÷100
sinaspect	Sin(aspect) x tan(slope); aspect in degrees, tan(slope) = slope %÷100
tan slope	Tan(slope) = slope %÷100
density	Number of trees taller than 1.4m per $375m^2$
BAR	The ratio, expressed as a decimal, of grand fir basal area to total basal area per $375m^2$ plot.
AVEBLC	The average height in meters to the base of the live crown among all trees taller than 1.4m within the $375m^2$ plot.
AVECRN	The average crown length in meters of all trees taller than 1.4m within the $375m^2$ plot.
SUMDIA	The sum of all diameters at breast height of trees taller than 1.4m within the $375m^2$ plot.
DBHTGF	The diameter espressed in centimeters of a grand fir of average grand fir basal area per $375m^2$ plot: $\sqrt{\frac{4}{\pi}\left(\frac{\text{total basal area x BAR}}{\text{No. of grand fir > 1.4m tall}}\right)} \times 100$

Table 11. Understory production linear multiple regression models based on 47 undamaged stands. Refer to table 12 for definitions of independent variables.

Vegetation Component	Regression coefficients for independent variables included in the linear regression models												
	Intercept	Cosaspect	Sinaspect	Tanslope	Density	Age	BA	BAR	LIVECRN	AVEHT	DBHTGF	ELEVATN	R^2
Total Production	12956.01	1232.61	-1084.73	-2496.31	236408.19	55.77	-2772.42	-10917.72	0	-482.28	0	0	0.5822648
Total Shrub	6368.94	-930.80	-255.97	-2086.18	0	29.22	-3027.78	-5775.92	72.45	0	0	0	0.3792644
Highly Preferred Shrubs	568.63	-50.74	-81.75	-46.42	-10059.32	-1.00	-223.91	-198.80	-4.40	0	27.65	0	0.4078257
Moderately Preferred Shrubs	5149.73	-140.64	-278.17	562.66	42910.04	15.57	0	-6414.00	0	-219.63	0	0	0.2503165
Least Preferred Shrubs	4778.53	88.22	-275.33	-1979.57	27037.11	0	-1895.81	0	0	0	0	0	0.4219415
Total Herbage	-513.10	1870.04	-165.50	-1022.83	145141.89	28.15	0	-5306.48	91.72	-252.91	0	0	0.6700520
Total Graminoids	-308.94	530.80	-337.82	74.50	48412.97	4.36	457.96	0	0	0	-97.04	0	0.4204572
Gramineae	-259.43	344.46	-269.90	110.15	34139.44	3.28	290.82	0	0	0	-65.09	0	0.4111183
Cyperaceae + Juncaceae	-49.51	186.35	-67.92	-35.65	14273.55	1.08	167.13	0	0	0	-31.95	0	0.4225043
Perennial Forbs	-1564.14	1359.12	243.25	-1316.04	132729.45	24.98	0	-3988.56	102.55	-228.15	0	0	0.6699450
Annuals	-5.25	-2.08	-0.49	-5.00	0	0.05	0	0	0	-0.19	0	0.00101	0.2915382
Allowable Forage Crop[1/]	1710.71	868.19	-188.12	-325.98	87781.33	20.95	0	-5882.19	62.70	-220.92	0	0	0.5902864

[1/] This model assumes a 50% proper use factor for total herbage and highly and moderately preferred shrubs.

Table 12. Definition of independent variables used in understory production models.

Variable	Definition
cosaspect	Cos(Aspect) x tan(slope); aspect expressed in degrees, tan(slope) = slope %÷100
sinaspect	Sine(Aspect) x tan(slope); aspect expressed in degrees, tan(slope) = slope %÷100
tan slope	Tan(slope) = slope percent ÷ 100
density	1/number of trees taller than 1.4 meters per $375m^2$ plot.
age	The mean age of 4 to 8 dominant and codominant trees per plot. It was not possible to represent all species present in the $375m^2$ plot.
BA	The basal area, in square meters at breast height, per $375m^2$ plot.
BAR	The ratio, expressed as decimal, of grand fir basal area to total basal area per $375m^2$ plot.
LIVECRN	The mean percent live crown; (mean crown length/mean tree height) x 100 was the method for calculating this value for each $375m^2$ plot.
AVEHT	The mean height of trees taller than 1.4 meters per $375m^2$ plot.
DBHTGF	The diameter (expressed in centimeters) of a grand fir of average grand fir basal area per $375m^2$ plot: $\sqrt{\frac{4}{\pi}\left(\frac{\text{Total BA x BAR}}{\text{No. of grand fir > 1.4m tall}}\right)\chi 100}$
ELEVATN	Elevation of the plot in feet.

Table 13. Coefficients of determination (R^2) and regression equations for estimating production (Y) of vegetation classes using sum of the diameters of trees (SD), overstory tree canopy coverage (CC) and basal area (BA) as independent variables in the Clearwater Mountains, Idaho.

Vegetation Class	Independent Variables	Model	R^2
Total Production minus Low Shrubs	CC	$\hat{Y} = -287.34 + 51936.96\ 1/CC$	.7658**
	SD	$\hat{Y} = 77.31 + 39449.64\ 1/SD$	.5489**
Tall Shrubs plus Selected Tall Shrubs	CC	$\hat{Y} = -414.87 + 42890.59\ 1/CC$	.7997**
	SD	$\hat{Y} = -132.27 + 35090.72\ 1/SD$	.6651**
	BA	$\hat{Y} = -56.14 + 5263.49\ 1/BA$	.3405**
Tall Shrubs	SD	$\hat{Y} = -140.54 + 29690.34\ 1/SD$	.6842**
	CC	$\hat{Y} = -325.42 + 31993.27\ 1/CC$	.6395**
	BA	$\hat{Y} = -71.16 + 4310.28\ 1/BA$	.3281**
Forbs	CC	$\hat{Y} = 380.01 - 2.24\ CC$	.3202**

**Significant at $\alpha \leq 0.01$.

APPENDIX B

Abstract from Abstracts of Papers presented at 30th Annual Meeting, Portland, Oregon, Society for Range Management, February 14-17, 1977:

UNDERSTORY PRODUCTION UNDER VARYING OVERSTORY CANOPY COVERAGES IN THE *ABIES GRANDIS-PACHISTIMA MYRSINITES* HABITAT TYPE OF NORTHCENTRAL IDAHO AND SOUTHEASTERN WASHINGTON

David A. Pyke and **Benjamin A. Zamora**, *Department of Forestry and Range Management, Washington State University, Pullman 99164.*

no mention of Ackn. to DFTM

A study was undertaken in the Clearwater Mountains of northcentral Idaho and the Blue Mountains of southeastern Washington to determine the relationship between herbage and browse production and forest canopy cover in the *Abies grandis-Pachistima myrsinites* habitat type. The purpose of the study was to develop models which could be used to assess long-term impact of partial overstory canopy coverage reduction on understory forage resources. Study plots were selected to represent a wide range of overstory canopy coverage and a disturbance-free understory strata. The production sampling was divided into five vegetation classes: selected species (*Acer glabrum, Amelanchier alnifolia, Berberis repens, Lonicera utahensis, Vaccinium membranaceum,* and the genus *Carex*); tall shrubs (excluding those listed as selected species); low shrubs (excluding *Berberis repens*); forbs; and graminoids (excluding the genus *Carex*). The analysis of the two areas was carried out independently to eliminate any edaphic or climatic biases which would have occurred.

In the Blue Mountains, forest canopy coverage is highly correlated with production of total vegetation, forbs, and tall shrubs plus selected shrub species. Correlation coefficients were −.93, −.85, and −.86 respectively. In the Clearwater Mountains, canopy coverage also shows strong correlations with production of tall shrubs, total vegetation (excluding low shrubs), and tall shrubs plus selected shrub species. These groups show correlation coefficients of −.75, −.86, and −.85, respectively. Inverse linear models were developed which document understory production-overstory cover relationships.

RELATIONSHIP BETWEEN OVERSTORY STRUCTURE AND UNDERSTORY PRODUCTION IN THE *ABIES GRANDIS-PACHISTIMA MYRSINITES* HABITAT TYPE OF NORTHCENTRAL IDAHO AND SOUTHEASTERN WASHINGTON

By

DAVID ALBERT PYKE

A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

WASHINGTON STATE UNIVERSITY
Department of Forestry and Range Management

1977

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of DAVID ALBERT PYKE find it satisfactory and recommend it be accepted.

_____
Chairman

_____

_____

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This study was supported by a research grant from the U.S. Department of Agriculture, Douglas-fir Tussock moth Research and Development Program.

I am extremely grateful to Dr. Benjamin Zamora for suggesting the research problem, providing guidance and increasing my knowledge of ecology. I wish to thank members of my graduate committee, Drs. Ben Roché and Donald Satterlund, for review of this thesis.

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To my fiancée, Debbie Miller, I am most grateful for her continuous encouragement and prayers throughout my graduate studies.

//Good girl!

RELATIONSHIP BETWEEN OVERSTORY STRUCTURE AND UNDERSTORY PRODUCTION IN THE *ABIES GRANDIS-PACHISTIMA MYRSINITES* HABITAT TYPE OF NORTHCENTRAL IDAHO AND SOUTHEASTERN WASHINGTON

ABSTRACT

by David Albert Pyke, M.S.
Washington State University, 1977

Chairman: Benjamin A. Zamora

A study was undertaken in the Clearwater Mountains of northcentral Idaho and the Blue Mountains of southeastern Washington to determine the relationship between herbage and browse production and overstory tree structure on undisturbed sites in the *Abies grandis-Pachistima myrsinites* habitat type. These relationships will provide a base line for future studies on areas which have been disturbed.

The overstory structures measured were: sum of the tree diameters, canopy cover, basal area, stand density and stand height. Study plots were selected to represent a wide range of these structural measures and an understory that was relatively disturbance free.

The understory production sampling was divided into five vegetation classes: (1) Selected species chosen on the basis of importance as livestock and wildlife forage and browse (*Acer glabrum*, *Amelanchier alnifolia*, *Berberis repens*, *Lonicera*

utahensis, Vaccinium membranaceum and the genus Carex); (2) Tall shrubs (excluding those listed as selected species); (3) Low shrubs (excluding Berberis repens); (4) Forbs; and (5) Graminoids (excluding the genus Carex).

In the northern Blue Mountains, sum of the tree diameters was significantly correlated with production of combined total herbage and browse, production of tall shrubs plus selected tall shrubs and forb production. Basal area was shown to be a significant predictor of production of graminoids excluding the genus Carex and production of tall shrubs by itself. Stand density was significantly correlated with the production of low shrubs.

In the Clearwater Mountains, canopy cover was shown to be a significant independent variable for production of combined total herbage and browse excluding low shrubs, production of tall shrubs including selected tall shrubs and forb production. Sum of the tree diameters was significantly correlated with tall shrub production by itself.

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INTRODUCTION

Multiple use management of forest resources is widely practiced on National Forests in the Pacific Northwest. Timber is the primary resource with secondary resources of livestock and wildlife. If managerial decisions for proper stocking levels of livestock and wildlife are to be made, then forage and browse production must be determined.

Forage and browse production is highly dependent on overstory stand structure. Studies have been conducted which relate understory production to overstory cover (Anderson et al., 1965; Cooper, 1960; Ehrenreich and Crosby, 1960; Halls and Shuster, 1965; Young et al., 1967) and basal area (Clary and Ffolliott, 1966; Gaines et al., 1954; Halls and Shuster, 1965). These relationships are important since timber stand measurements can provide a practical means of predicting understory production.

In the Pacific Northwest, these relationships need to be established for the major forest habitat types. By developing these relationships for habitat types, variation of understory production due to general site factors will be reduced. The Abies grandis-Pachistima myrsinites habitat type (Daubenmire and Daubenmire, 1968) is one of the more productive and widely occurring types in the Blue Mountains and the Clearwater Mountains and receives considerable summer use by big game and livestock.

The objective of this study was to determine relationships between overstory structure and understory production on undisturbed Abies grandis-Pachistima myrsinites habitat type in the Blue Mountains and the Clearwater Mountains. This will provide a base line for future studies of these relationships on areas which have been disturbed.

STUDY AREAS AND METHODS

Study plots were located in the Clearwater Mountains, Nezperce National Forest, northcentral Idaho and in the northern Blue Mountains, Umatilla National Forest, southeastern Washington. The plots in the Clearwater Mountains were located at elevations ranging from 1120 m to 1620 m, with aspects representing all the cardinal directions and slopes ranging from 0% to 54%. The plots in the Blue Mountains were located at elevations ranging from 1190 m to 1700 m, with slopes between 8% to 48% and north to southeast aspects, with the exception of one northwest facing plot. Slope position was divided into six categories: (1) ridge; (2) bench or flat; (3) upper slope; (4) mid-slope; (5) lower slope; and (6) stream bottom, while the slope configuration was divided into four categories: (1) convex; (2) concave; (3) straight; and (4) undulating. The general plot descriptions are summarized in Appendix A, Tables 3 and 4 for the northern Blue Mountains and Clearwater Mountains respectively.

Appendix A, Tables 5 and 6 show climatic data for the three closest permanent climatological stations that surround the northern Blue Mountains and Clearwater Mountains respectively. This information shows that the Clearwater Mountains are cooler and wetter than the Blue Mountains.

Twenty-nine sample areas were chosen for this study. Twenty sample areas are located in the Clearwater Mountains and nine in the Blue Mountains. Nine of the plots in the Clearwater Mountains represented undisturbed sites and the remaining eleven were logged 21 to 29 years previous. However all sites contained representive understories of the Abies grandis-Pachistima myrsinites habitat type. Nine plots are located in the Blue Mountains in stands characterized by undisturbed understory.

Locations of the circular, 375 m^2, macroplots were selected to obtain a range in overstory canopy cover, sum of the tree diameters, basal area, stand height and stand density. Overstory canopy coverage was measured using a spherical densiometer (Lemmon, 1956) leveled at one meter above the ground. Diameter at breast height was measured for all conifer trees over 1.4 m high and used to calculate the basal area in m^2/ha and sum of the diameters in m/ha. Average height of the combined dominant and codominant crown classes was measured with a clinometer to determine the stand height in m. Stand density was the number of trees per hectare (# trees/ha).

Understory production was determined by modifying a method developed by W.F. Mueggler (1976). Ten, 4.8 square foot, production microplots were placed in a systematic randomized fashion within each macroplot. Two, two-man teams were used in the sampling with each team clipping one 4.8 square foot microplot and estimating four microplots as a percentage of the clipped microplot.

Estimation error was assessed by clipping all ten microplots for three of the twenty-nine macroplots. An equation was derived which adjusted the estimation prior to calculating the production for each plot.

The production was sampled between August 9 and 17, 1976. This was estimated to be the period of maximum above-ground production for the year. Total current years growth was clipped and estimated for herbage and browse. The production sampling was divided into five vegetation classes: (1) Selected species chosen on the basis of importance as livestock and wildlife forage and browse (Acer glabrum, Amelanchier alnifolia, Berberis repens, Lonicera utahensis, Vaccinium membranaceum and the genus Carex); (2) tall shrubs (excluding those listed as selected species); (3) low shrubs (excluding Berberis repens); (4) forbs; and (5) graminoids (excluding the genus Carex).

The clippings were brought to the laboratory where they were air-dried for three days, oven-dried for 12 hours at 60°C, weighed and converted from grams per microplot to kilograms per hectare.

Relationships between overstory structure and production of each vegetation class with constancy greater than 50% were analyzed using the REGR procedure of the Statistical Analysis System (Barr and Goodnight, 1972). The program determined the statistical significances of the relationships and developed linear models by applying the principle of least squares.

RESULTS AND DISCUSSION

The results will be presented under five major headings: (1) Combined total herbage and browse production; (2) Shrub production; (3) Forb production; (4) Graminoid production; and (5) Production of selected species. The significant relationships for a specific vegetation class will be shown for the northern Blue Mountains then the Clearwater Mountains. Discussion of the relationships will follow.

Physiographic features and climatological data for each study site are listed in Appendix A. Measurements of the overstory structure are provided in Appendix B and mean herbage and browse production separated by vegetation classes are listed by macroplot in Appendix C. Plant species which occured on the study sites are listed by vegetation class in Appendix C.

Combined Total Herbage and Browse Production

The highest correlation in the northern Blue Mountains was found to be between the sum of the tree diameters and combined total herbage and browse production. The curvilinear relationship expressed in Table 1 and illustrated in Fig. 1 accounts for 93% of the variation of total herbage and browse production.

The relationship between overstory canopy cover and combined total herbage and browse production is the only other

Table 1. Coefficients of determination (R^2) and regression equations for estimating production (Y) of vegetation classes using sum of the diameters of trees (SD), overstory tree canopy coverage (CC), basal area (BA) and stand density of trees (DE) as independent variables in the Blue Mountains, Washington.

Vegetation Class	Independent Variables	Model	R^2
Total Production	SD	$\hat{Y} = 386.30 + 14978.98\ 1/SD - 1.11\ SD$	.9297**
	CC	$\hat{Y} = 904.76 - 8.75\ CC$	.8415**
Graminoids excluding the genus Carex	BA	$\hat{Y} = -1.99 + 124.92\ 1/BA$	.8758**
Tall Shrubs plus Selected Tall Shrubs	SD	$\hat{Y} = 117.20 + 368.88\ 1/SD - 0.35\ SD$	.8136**
	CC	$\hat{Y} = 194.30 - 1.99\ CC$	.7908**
Vaccinium membranaceum	SD	$\hat{Y} = 130.35 - 1839.52\ 1/SD - 0.38\ SD$	.8127**
	CC	$\hat{Y} = 155.87 - 1.54\ CC$	.6482**
Forbs	SD	$\hat{Y} = 185.62 + 10762.53\ 1/SD - 0.48\ SD$	.8102**
	CC	$\hat{Y} = 472.95 + 479.89\ 1/CC - 4.35\ CC$	.6735**
Tall Shrubs	BA	$\hat{Y} = 71.46 - 41.01\ (\log BA)$	.7244**
	CC	$\hat{Y} = -17.53 + 1596.81\ 1/CC - 0.002\ CC$	.6612**
Low Shrubs	DE	$\hat{Y} = 460.44 - 131.23\ (\log DE)$	.6774**

**Significant at $\alpha \leq 0.01$.

$$Y = 386.30 + 14978. / X - 1.11 X$$

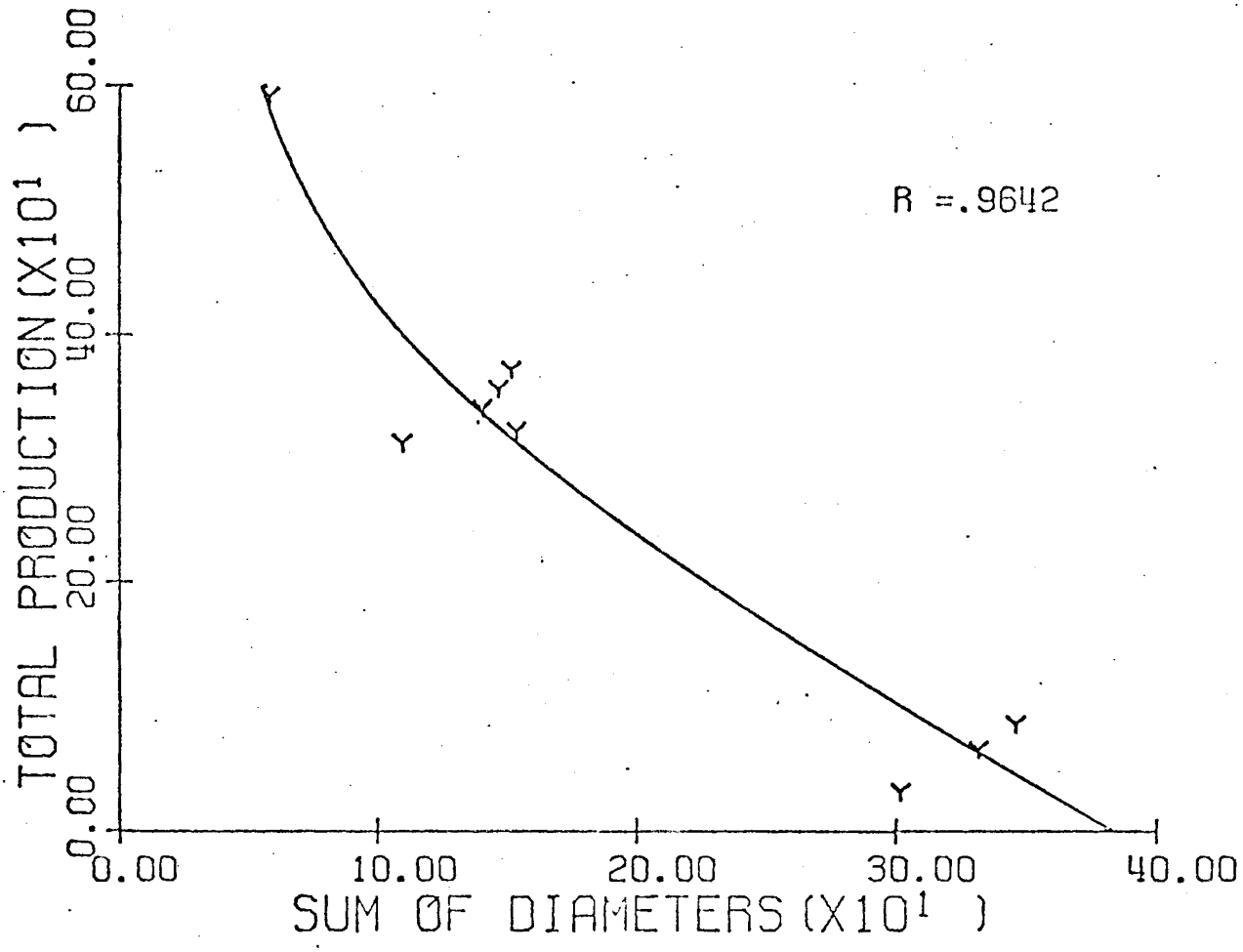

Fig. 1. Correlation coefficient and relationship of combined total herbage and browse production (kg/ha) to sum of the tree diameters (m/ha) in the northern Blue Mountains, Washington.

significant relationship for the northern Blue Mountains (Table 1). This linear relationship accounts for 84% of the variation of total herbage and browse production.

Combined total herbage and browse production in the Clearwater Mountains was not significantly correlated with any overstory structure. This was not anticipated when the study was set up and further anlaysis showed that low shrub production was highly variable ($\bar{x}$=272 kg/ha, s=450 kg/ha).

By removing the low shrub production values from the total herbage and browse production, a significant relationship was established between combined production of total herbage and browse and overstory tree canopy cover.

Table 2 shows the model which was developed for overstory tree canopy cover and combined production of total herbage and browse excluding low shrubs. This relationship accounts for 80% of the variability of the production of total herbage and browse excluding low shrubs. The model illustrates that at 50% and 100% overstory tree canopy cover, the production will be 751 kg/ha and 232 kg/ha respectively (Fig. 2).

A significant curvilinear relationship was also found between combined production of total herbage and browse and sum of the tree diameters for the Clearwater Mountains (Table 2). This model accounts for only 55% of the variation of the combined production of total herbage and browse excluding low shrubs.

In the northern Blue Mountains, the model for the relationship between browse production and sum of the tree diameters

Table 2. Coefficients of determination (R^2) and regression equations for estimating production (Y) of vegetation classes using sum of the diameters of trees (SD), overstory tree canopy coverage (CC) and basal area (BA) as independent variables in the Clearwater Mountains, Idaho.

Vegetation Class	Independent Variables	Model	R^2
Total Production minus Low Shrubs	CC	$\hat{Y} = -287.34 + 51936.96\ 1/CC$	.7658**
	SD	$\hat{Y} = 77.31 + 39449.64\ 1/SD$	.5489**
Tall Shrubs plus Selected Tall Shrubs	CC	$\hat{Y} = -414.87 + 42890.59\ 1/CC$	.7997**
	SD	$\hat{Y} = -132.27 + 35090.72\ 1/SD$	.6651**
	BA	$\hat{Y} = -56.14 + 5263.49\ 1/BA$	.3405**
Tall Shrubs	SD	$\hat{Y} = -140.54 + 29690.34\ 1/SD$	.6842**
	CC	$\hat{Y} = -325.42 + 31993.27\ 1/CC$	.6395**
	BA	$\hat{Y} = -71.16 + 4310.28\ 1/BA$	.3281**
Forbs	CC	$\hat{Y} = 380.01 - 2.24\ CC$	.3202**

**Significant at $\alpha \leq 0.01$.

$$Y = -287.3 + 51936. / X$$

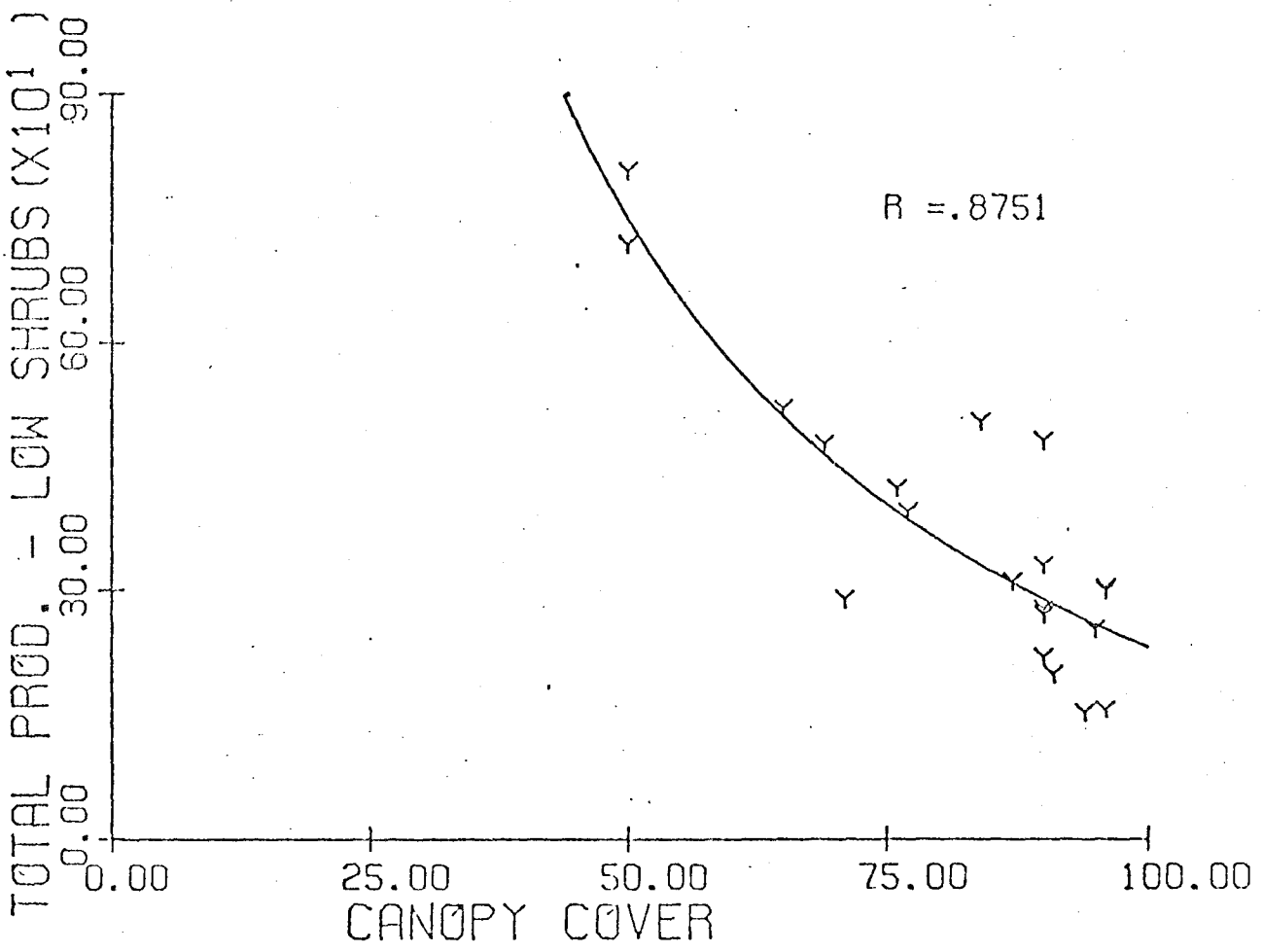

Fig. 2. Correlation coefficient (r) and relationship of total herbage and browse production excluding low shrubs (kg/ha) to overstory canopy cover (%) in the Clearwater Mountains, Idaho.

is inaccurate for high values of sum of the tree diameters. Figure 1 indicates that in a stand with a 383 m/ha sum of the tree diameters, the total herbage and browse production would be zero. In actuality the production will be extremely low in stands with high values for sum of the tree diameters and since the understory includes shade tolerant plants such as Viola orbiculata, Pyrola secunda and Chimaphila umbellata it is doubtful that an area would be sterile of all herbage and browse.

Clary and Ffolliott (1966) found a logarithmic curvilinear relationship ($Y = A + B \log X$) between basal area and total herbage production in Pinus ponderosa forests of Arizona. In the Blue Mountains and the Clearwater Mountains, basal area was not a significant means of establishing a relationship between overstory stand structure and total herbage and browse production.

The total production for the Clearwater Mountains is over twice the total production of the northern Blue Mountains. This is partially due to the lack of Xerophyllum tenax in the Blue Mountains. If low shrub production, which includes Xerophyllum tenax, is removed from the total production in the Clearwater Mountains, there still is a greater amount of total herbage and browse production in the Clearwater Mountains. This may be partially explained by the greater amount of precipitation that the Clearwater Mountains receive. Another factor which might effect the production is nutrient availability. Moir (1966) speculated that decreases in production

$$Y = 117.20 + 368.88 / X - 0.35 X$$

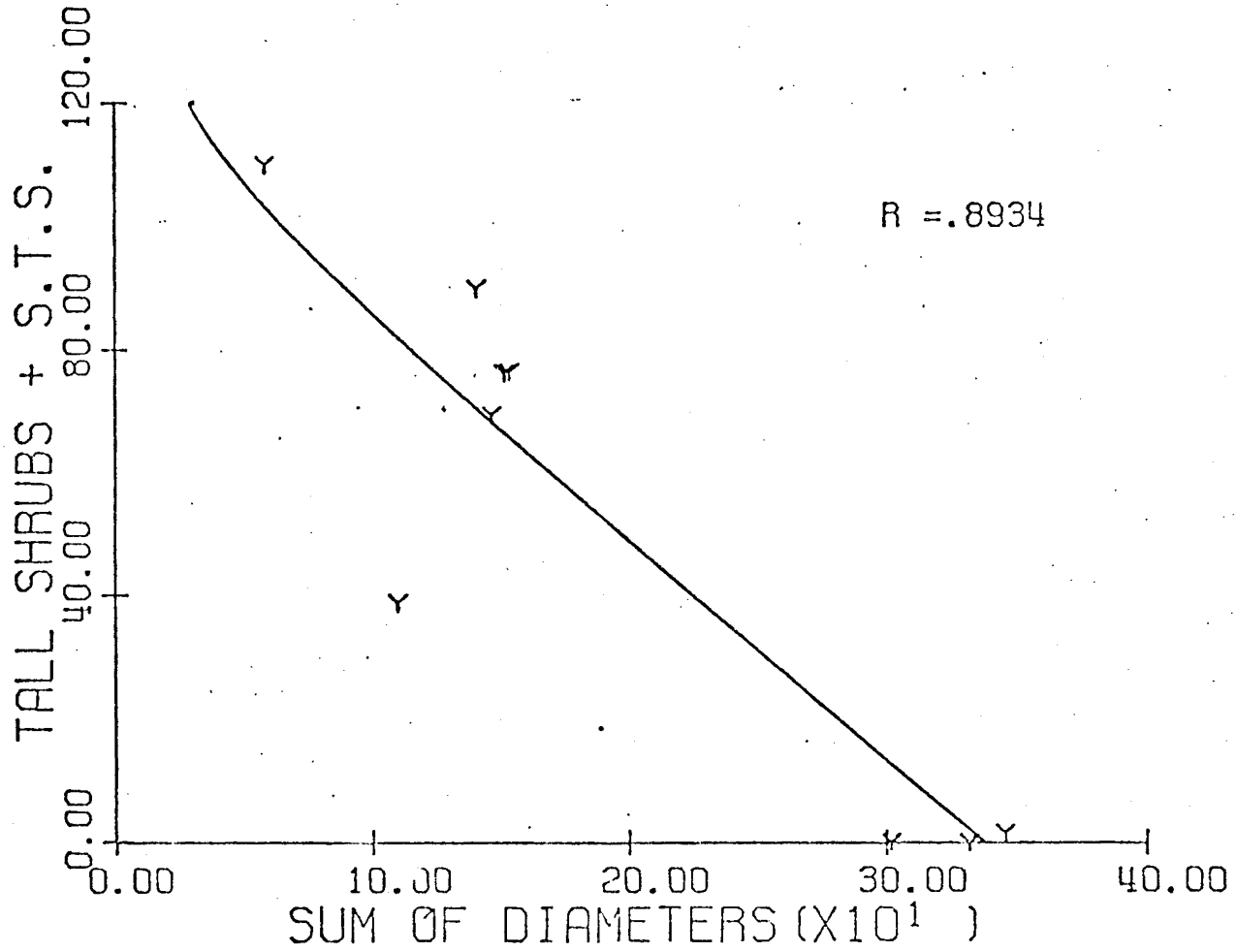

Fig. 3. Correlation coefficient and relationship of production of tall shrubs including selected tall shrubs (S.T.S.) (kg/ha) to sum of the tree diameters (m/ha) in the northern Blue Mountains, Washington.

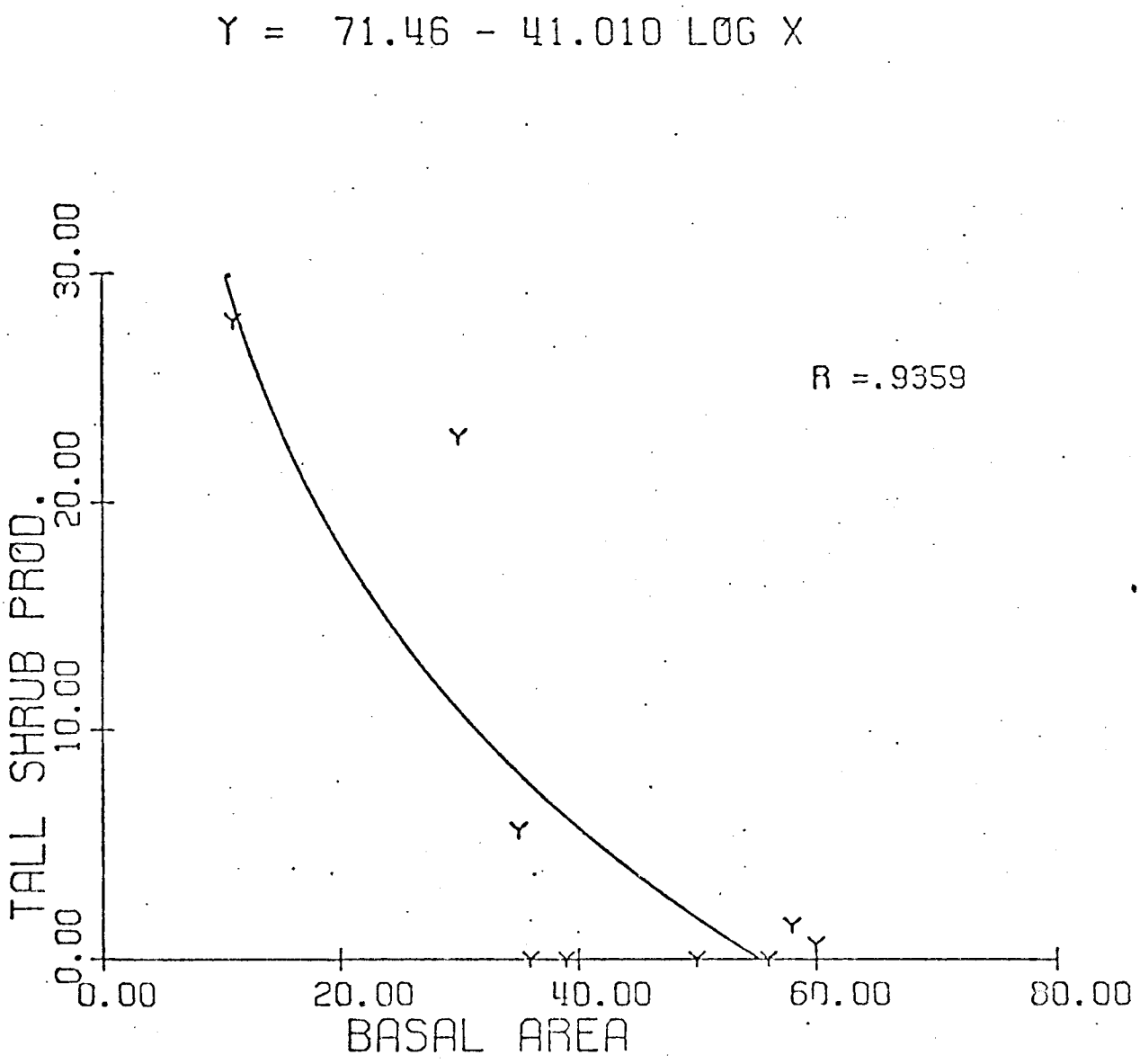

Fig. 4. Correlation coefficient and relationship of tall shrub production (kg/ha) to basal area (m^2/ha) in the northern Blue Mountains, Washington.

from open to dense ponderosa pine sites may be due to soil nutrient deficiencies caused by tree retention of nutrients. Nutritional differences similar to this may be the cause of production differences between the two areas.

Shrub Production

In the northern Blue Mountains, selected tall shrubs were included in the tall shrub catagory to determine what relationships exist between tall shrubs as a collective vegetation class and overstory structure. Sum of the tree diameters is highly correlated (r=0.9144) with production of tall shrubs including selected tall shrubs (Acer glabrum, Amelanchier alnifolia, Lonicera utahensis, and Vaccinium membranaceum). A curvilinear relationship was established which accounts for 81% of the total variation of production of tall shrubs including selected tall shrubs (Table 1, Fig. 3).

The relationship between production of tall shrubs including selected tall shrubs and overstory tree canopy cover was also found to be significant (Table 1). This relationship accounts for only 70% of the variation in the production of tall shrubs including selected tall shrubs.

The relationship between tall shrubs excluding the selected tall shrubs and basal area in the northern Blue Mountains (Table 1) explains 72% of the total variation that exists for the production of this vegetation class. The model which gave the best fit was the log formula shown in Fig. 4. This suggests that at 55 m^2/ha the production of tall shrubs excluding selected tall shrubs will be zero.

The only other significant relationship with tall shrub production in the Blue Mountains occured with overstory tree canopy coverage (Table 2). This curvilinear relationship explains 66% of the total variation of tall shrub production.

The strongest correlation in the Clearwater Mountains was found between overstory canopy cover and the production of tall shrubs including selected tall shrubs (Table 2, Fig. 5). This curvilinear relationship explains 80% of the total variation that occurs in the production of tall shrubs and selected tall shrubs.

Two other measured overstory structures in the Clearwater Mountains which were significantly correlated with the production of tall shrubs including selected tall shrubs were sum of the tree diameters and basal area (Table 2). The relationship with sum of the tree diameters explains 67% of the total variation of the production of tall shrubs including selected tall shrubs while the basal area relationship only explains 34% of the variation.

Tall shrub production excluding the selected tall shrub production showed a strong correlation with the sum of the tree diameters. Table 2 and Fig. 6 illustrate the model with 68% of the variation explained by this relationship. The tall shrub production reduces to zero at a sum of the tree diameters of 211 m/ha.

Overstory tree canopy cover and basal area are both significantly related to tall shrub production (Table 2). The

$$Y = -414.8 + 42890. / X$$

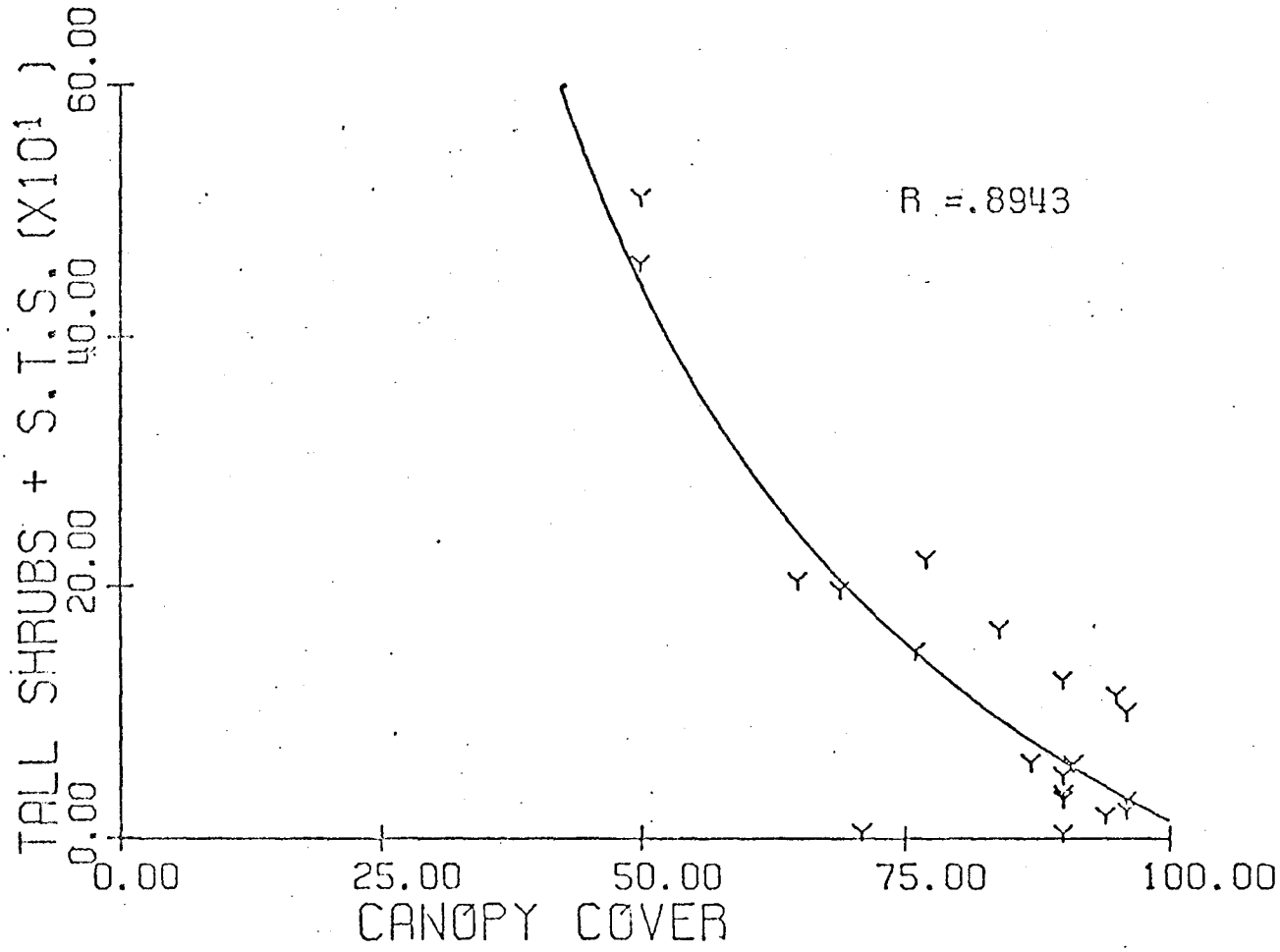

Fig. 5. Correlation coefficient (r) and relationship of production of tall shrubs including selected tall shrubs (S.T.S.) (kg/ha) to overstory canopy cover (%) in the Clearwater Mountains, Idaho.

$$Y = -140.5 + 29690. / X$$

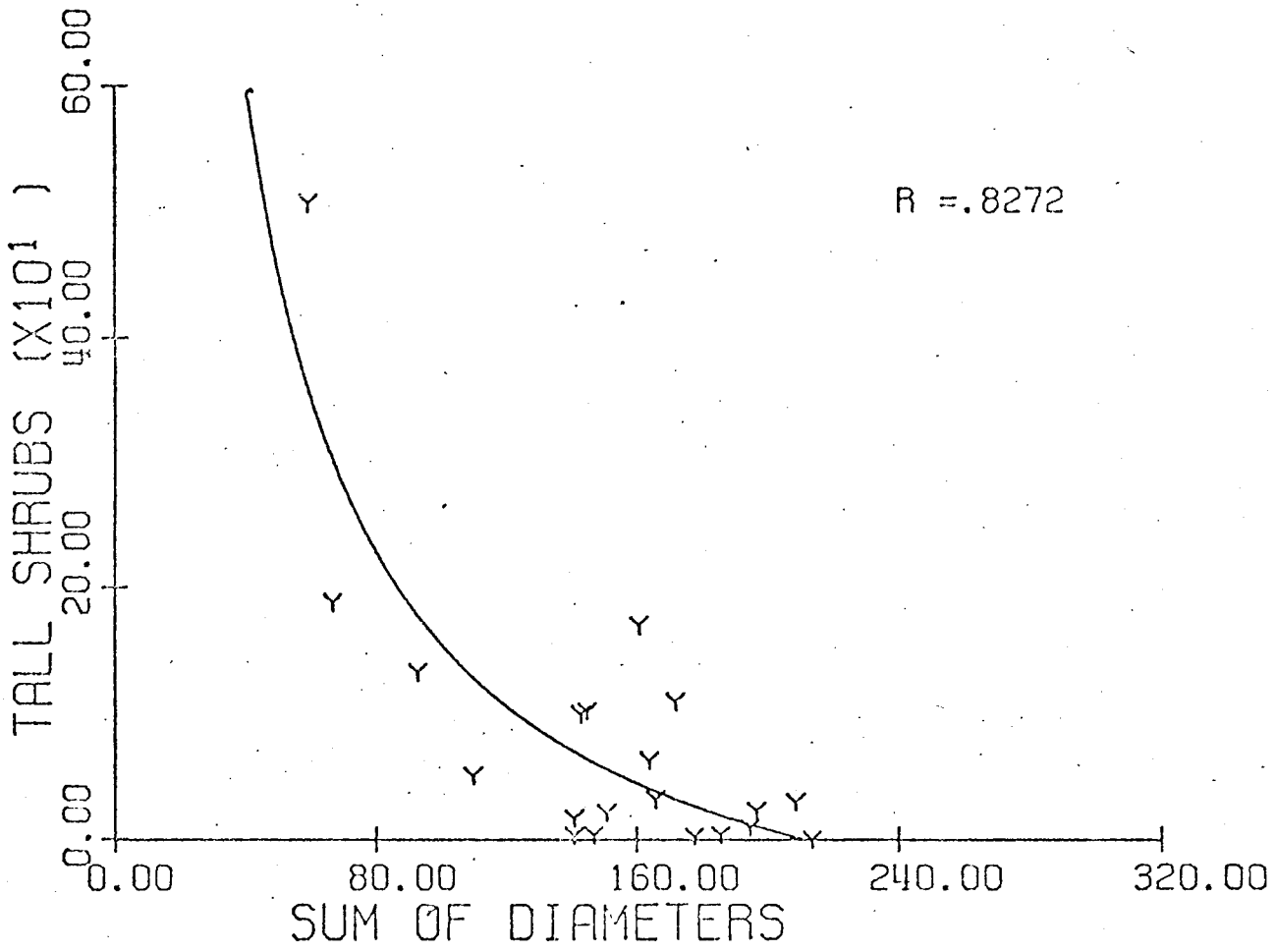

Fig. 6. Correlation coefficient (r) and relationship of production of tall shrubs excluding selected tall shrubs (kg/ha) to sum of the tree diameters (m/ha) in the Clearwater Mountains, Idaho.

model using overstory tree canopy coverage accounts for 64% of the variation in tall shrub production while the basal area model only accounts for 33%.

In work conducted by Young et al. (1967) on mixed conifer forests in northeastern Oregon, production of shrub current annual growth, as a percentage of the total herbage and browse production, peaked at 20% for an overstory canopy cover class of 21-35%. The data for my study in the Blue Mountains shows a peak of 24% production occuring at a 51-65% canopy cover class (Fig. 7). At the high canopy class Young et al. found approximately 8% shrub production where my data showed only 0.5%. The Clearwater Mountains data cannot be graphically compared using this method since there is a lack of information in the lower crown cover classes, but in the upper two classes it does show a higher percentage shrub production than either the northern Blue Mountains data or the data of Young et al.

The only significant relationship for low shrub production in the northern Blue Mountains utilized stand density as its independent variable (Table 1). A logarithmic model, illustrated in Fig. 8, accounts for 68% of the total variation in the low shrub production.

Low shrub production in the Clearwater Mountains was not significantly correlated with any measured overstory variable. Adjustments of this class by including the production of Berberis repens (Appendix C, Table 13) still did not result in statistically significant linear or curvilinear models.

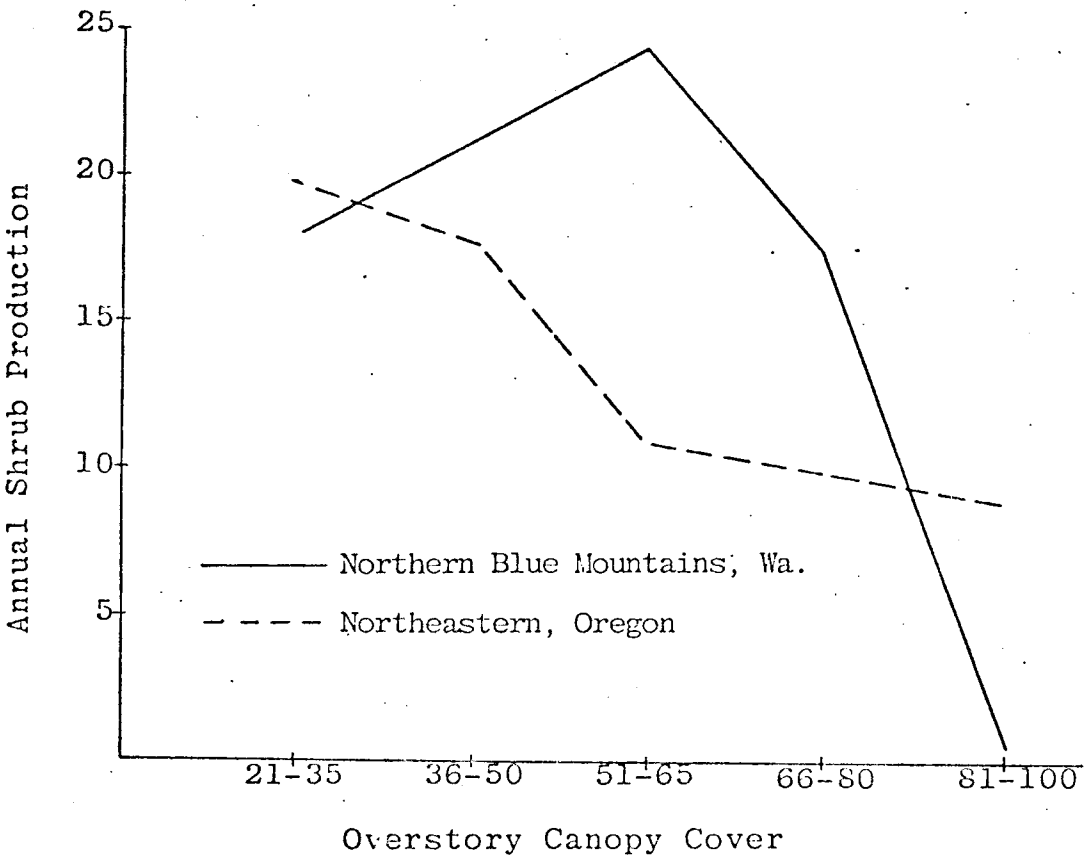

Fig. 7. Comparison of annual shrub production as a percentage of the total herbage and browse production to overstory canopy cover (%) for northeastern Oregon (Young et al., 1967) and the northern Blue Mountains, Washington.

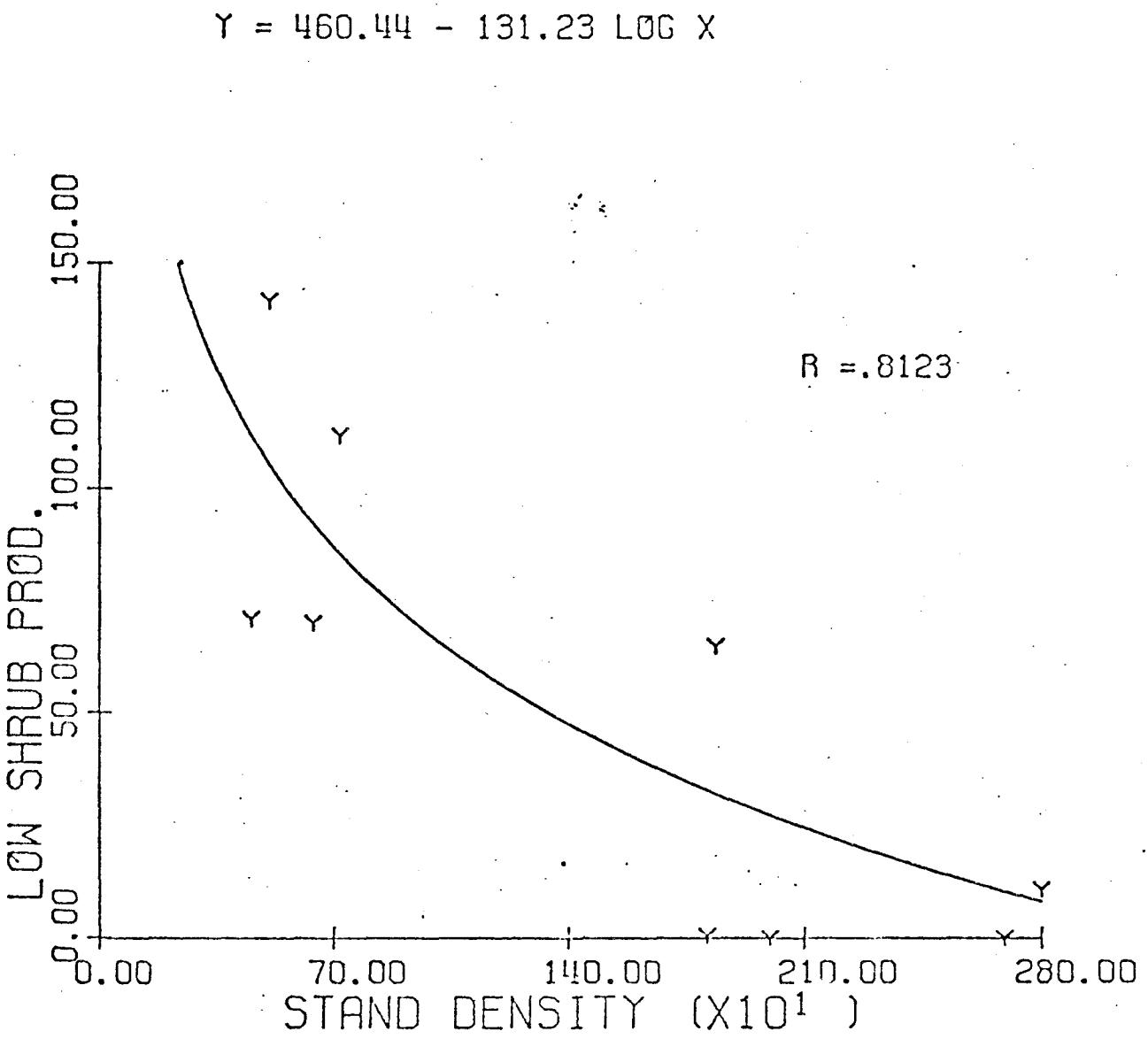

Fig. 8. Correlation coefficient and relationship of low shrub production (kg/ha) to stand density (# trees/ha) in the northern Blue Mountains, Washington.

Low shrub production in the northern Blue Mountains is significantly lower than low shrub production in the Clearwater Mountains (α=0.01). This is likely due to the Xerophylum tenax which does not occur in the northern Blue Mountians. The reason for the lack of Xerophylum tenax in the northern Blue Mountains may be due to the low rainfall in this area as compared to the Clearwater Mountains or some other little known autecological factor of this plant.

Forb Production

A significant relationship between the sum of the tree diameters and forb production in the northern Blue Mountains was established. Eighty-one percent of the total variation in forb production is explained by this relationship (Table 1). Figure 9 shows the fit of this model through the range of data that were collected.

The relationship between forb production and overstory tree canopy cover was the only other significant relationship for this vegetation class in the northern Blue Mountains (Table 1). This model accounts for 67% of the total variation of forb production.

The lowest correlation coefficient for a significant relationship in the Clearwater Mountains was 0.5658 for forb production and overstory tree canopy cover. This was the only linear model (Table 4, Fig. 10) that was significant in the Clearwater Mountains. This relationship accounts for only 32% of the variability in forb production, however even at this low

$$Y = 185.62 + 10762. / X - 0.48 X$$

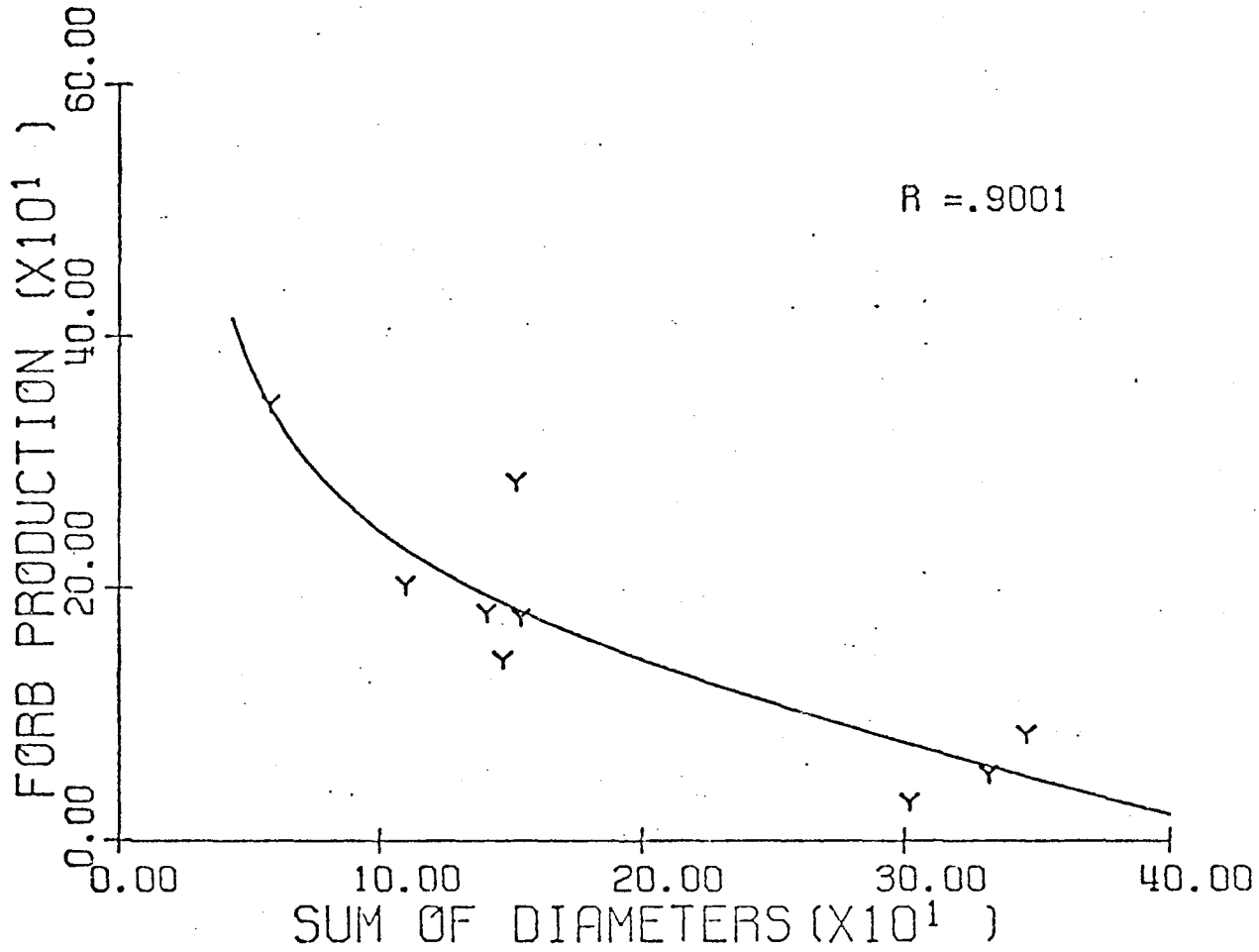

Fig. 9. Correlation coefficient and relationship of forb production (kg/ha) to sum of the tree diameters (m/ha) in the northern Blue Mountains, Washington.

$$Y = 380.01 - 2.2400 * X$$

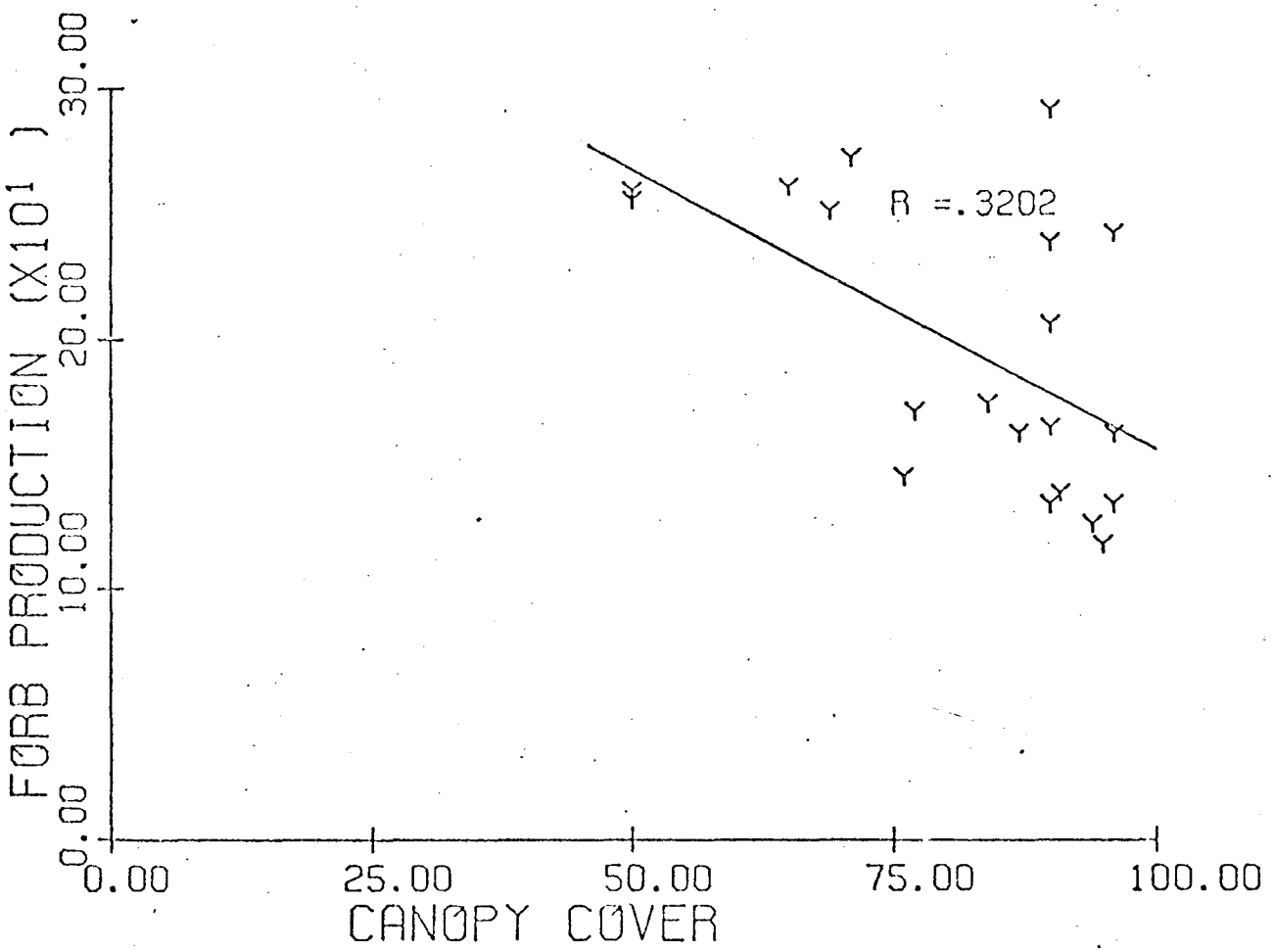

Fig. 10. Correlation coefficient (r) and relationship of forb production (kg/ha) to overstory canopy cover (%) in the Clearwater Mountains, Idaho.

level of accountability the model is statistically significant at the 99% confidence level.

None of the other measured overstory structures were significantly correlated with forb production in the Clearwater Mountains.

Forbs in the northern Blue Mountains can be considered the primary producer of the understory since a mean 69% of the total herbage and browse production can be attributed to forbs. In the Clearwater Mountains forbs account for a mean of 40%, which is still the highest percentage of any vegetation class. The decrease of forb production in the Clearwater Mountains may be due to the increase in the production of low shrubs.

Little work has been done on relating forb production exclusively with overstory tree structure, but by extracting data from the northeastern Oregon study by Young et al. (1967) mentioned previously, it was shown that a heavy shade overstory cover class produced 38 kg/ha. Stands with a sum of the tree diameters of 350 m/ha recorded for the northern Blue Mountains produced 45 kg/ha. The Clearwater Mountains yield 158 kg/ha which is much higher than either that of the northern Blue Moutains or that reported by Young et al.

The forb production in the Clearwater Mountains is similar to the forb production in the Missouri Ozarks low-grade hardwood stands which were investigated by Ehrenreich and Crosby (1960). They found a linear relationship between hardwood crown cover and forbs. The values ranged from approximately 210 lbs/ac at 50% cover to 175 lbs/ac at 94% cover. The

Clearwater data are also a linear relationship with overstory canopy cover. Its range of forb production values are from 268 kg/ha at 50% cover to 169 kg/ha at 94% cover.

Graminoid Production

Graminoid production in the northern Blue Mountains is poorly correlated with measured overstory structural features with the exception of basal area (Table 1, Fig. 11). This relationship explains 87% of the total variation that occurs in graminoid production.

In the Clearwater Mountains, graminoid production was not signficantly correlated with any overstory structures.

Graminoid production in the northern Blue Mountains seems to substantiate results of Cooper (1960) in the ponderosa pine forests of Arizona and Young et al. (1967) in the mixed-conifer forest of northeastern Oregon. Cooper showed grass production to be zero in dense stands of ponderosa pine. Data extracted from the Young et al. study show that for grasses other than Calamagrostis rubescens, which seems to tolerate shade, the production is less than 10 lbs/ac.

The graminoid production in the Clearwater Mountains, with a mean production of 33 kg/ha is significantly higher than the 1.8 mean production in the Blue Mountains (α=0.01). The increased precipitation in the Clearwater Mountains may have some influence on the production but with such a large difference between the two areas it is likely that other factors such as nutrients play a major role. The retention of calcium by Abies

$$Y = -1.99 + 124.92/BA$$

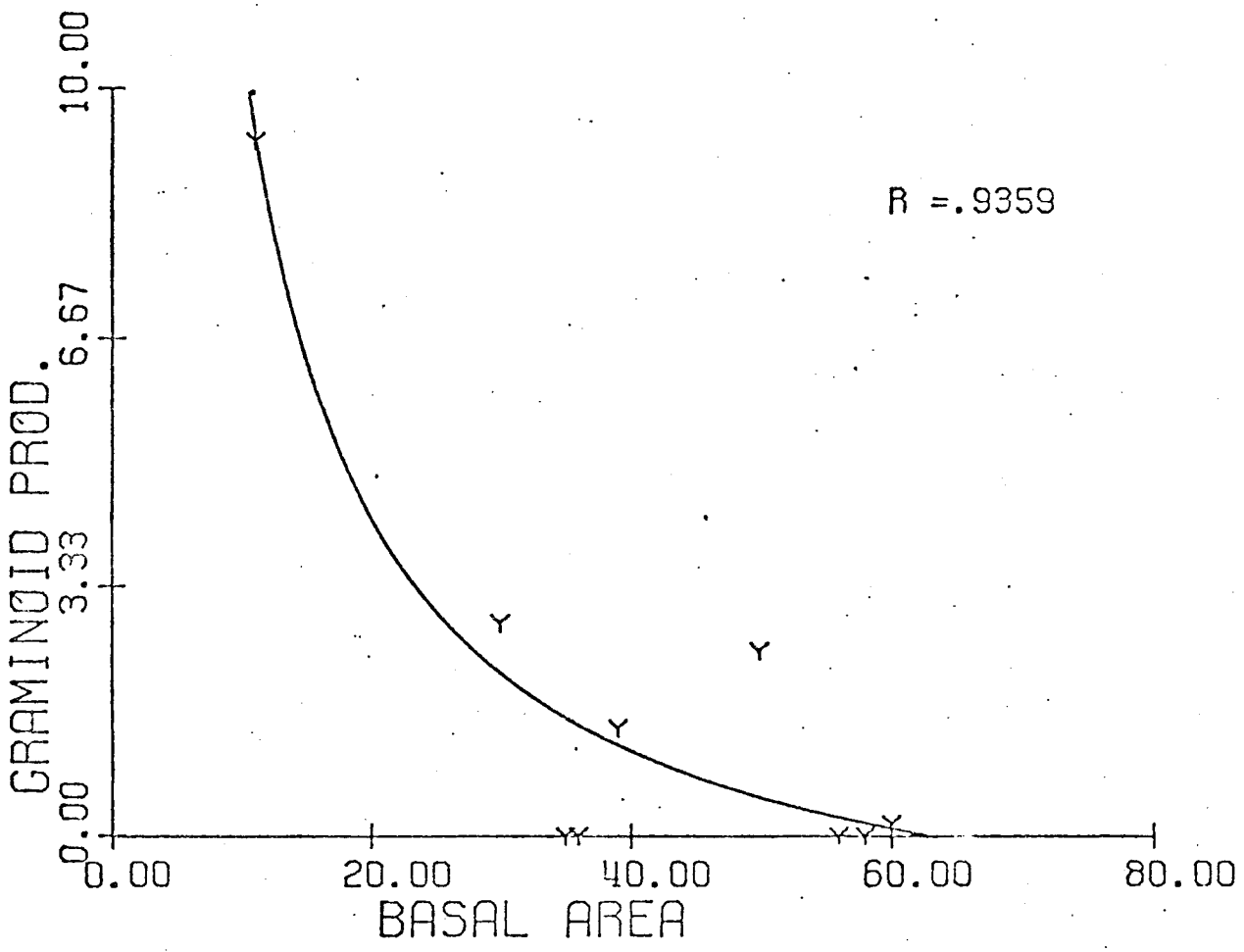

Fig. 11. Correlation coefficient and relationship of graminoid production (kg/ha) to basal area (m^2/ha) in the northern Blue Mountains, Washington.

grandis needles and the high acid condition of Abies grandis soils, (Daubenmire, 1953) may be determining factors in production of both the Blue Mountains and the Clearwater Mountains.

Production of Selected Species

All of the selected species in the northern Blue Mountains, with the exception of Vaccinium membranaceum, had constancies less than 50% consequently it was the only species considered in analysis (Appendix C, Table 10). Table 1 and Fig. 12 show the statistically significant relationship between sum of the tree diameters and production of Vaccinium membranaceum, which accounts for 81% of the total variation of the production of Vaccinium membranaceum.

The only other significant relationship for Vaccinium membranaceum was with overstory tree canopy cover (Table 1). This linear relationship accounts for the 65% of the variation of the Vaccinium membranaceum production.

In the model with sum of the tree diameters, Vaccinium membranaceum a downward trend in the curve beginning around 75 m/ha (Fig. 12). This trend may be artificial due to the low number of samples at this extreme or Vaccinium membranaceum may decrease with decreasing sum of the tree diameters beyond this point. Young et al. (1967) showed a downward trend in shrub production in an open overstory canopy cover class in northeastern Oregon.

$$Y = 130.35 - 1839.5 / X - 0.38 X$$

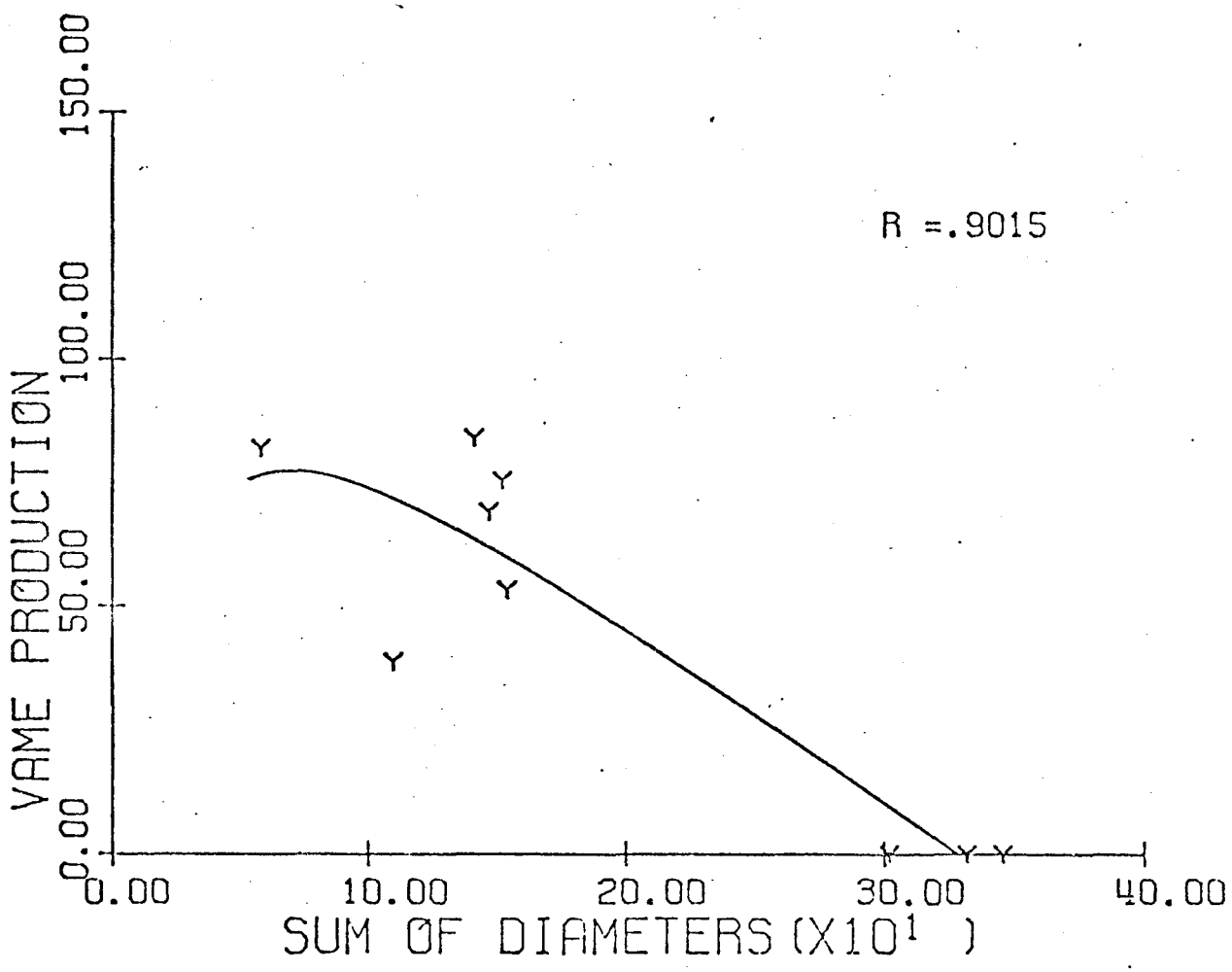

Fig. 12. Correlation coefficient and relationship of Vaccinium membranaceum production (kg/ha) to sum of the tree diameters (m/ha) in the northern Blue Mountains, Washington.

note: Try to find one mention of DFTM in this most important section!

SUMMARY AND CONCLUSIONS

This study suggests that canopy cover, sum of the tree diameters, stand density and basal area are the best predictors of understory production on the Abies grandis-Pachistima myrsinites habitat type in the northern Blue Mountains, southeastern Washington and the Clearwater Mountains, northcentral Idaho. Models developed using stand height showed poor correlations with all vegetation classes. The sum of the tree diameters and canopy cover have been correlated to light intensity and net radiation but basal area shows poorer correlations (Reifsynder and Lull, 1965). This may indicate that the vegetation classes which were related to sum of the tree diameters and canopy cover were more related to light intensity or net radiation while those related to basal area may be influenced by factors other than light.

The models which have been developed for the northern Blue Mountains and the Clearwater Mountains are considered specific to the areas for which they were derived and to the range of values of the independent variable in the model. The models have not been tested outside these areas on other Abies grandis-Pachistima myrsinites sites. Any extension of these models to lower or higher values may result in false predictions.

In the northern Blue Mountains, sum of the tree diameters was significantly correlated with production of combined total

herbage and browse, production of tall shrubs plus selected tall shrubs and forb production. Basal area was shown to be a significant predictor of production of graminoids excluding the genus Carex and production of tall shrubs by itself. Stand density was significantly correlated with the production of low shrubs.

Overstory tree canopy cover associated with the combined production of total herbage and browse, production of tall shrubs plus selected tall shrubs, production of tall shrubs by itself, production of forbs and production of Vaccinium membranaceum formed significant secondary relationships in the northern Blue Mountains.

In the Clearwater Mountains, canopy cover was shown to be a significant independent variable for production of combined total herbage and browse excluding low shrubs, production of tall shrubs including selected tall shrubs and forb production. Sum of the tree diameters was significantly correlated with tall shrub production by itself.

For the secondary relationships in the Clearwater Mountains, sum of the tree diameters was the significant independent variable for production of combined total herbage and browse, and production of tall shrubs including selected tall shrubs. Overstory tree canopy cover was significant for production of tall shrubs by itself. Basal area formed significant tertiary relationships with production of tall shrubs including selected tall shrubs and production of tall shrubs by itself.

The relationship between stand density and low shrub production in the northern Blue Mountains as shown in this study is statistically significant but logic indicates that this relationship may not hold for the extreme values of stand density. A stand density of 1000 trees/ha of 3 m tall trees will not have the same effect on the understory as 1000 trees/ha of 30 m tall trees. Future studies should consider combining stand density with other overstory structures to increase the predictive powers of models.

Additional studies need to be conducted in the northern Blue Mountains and the Clearwater Mountains with emphasis on sampling the lower extremes of overstory structures in undisturbed stands. Locating such stands may be very difficult since undisturbed Abies grandis sites tend to have relatively closed canopies entering the sere late in succession.

From a managerial standpoint, the next study should relate understory production to different logging intensities for each distinct logging practice. That study would evaluate disturbance factors on these Abies grandis sites. A useful addition to this project would be the relationship of production to time since disturbance. That would provide the manager of an area an approximate time table for understory production of a period after disturbance.

From a synecological standpoint a study is needed to determine why the Clearwater Mountains produce more than the Blue Mountains on the same habitat type. Consequently, such a study should include accurate climatological data from within

the study area, an analysis of the impact of litter, and an evaluation of soil fertility.

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APPENDIX A

PHYSIOGRAPHIC FEATURES AND CLIMATOLOGICAL DATA FOR EACH STUDY SITE

Table 3. Topographic features of plots in the Blue Mountains, Washington.

Plot Number	Elevation (m)	Aspect (degrees)	Slope (%)	Slope Configuration[1]	Slope Position[2]
1	1560	106	9	UN	U
7	1355	7	8	UN	R
19	1480	34	10	UN	R
21	1560	60	10	ST	R
26	1700	120	21	UN	U
39	1270	27	26	ST	L
40	1190	129	21	CN	L
44	1560	37	48	CN	L
45	1530	319	42	CN	U

[1]Slope Configuration: CV = Convex; CN = Concave; ST = Straight; UN = Undulating.

[2]Slope Position: U = Upper 1/3; M = Middle 1/3; L = Lower 1/3; R = Ridge; B = Bench; S = Stream bottom.

Table 4. Topographic features of plots in the Clearwater Mountains, Idaho.

Plot Number	Elevation (m)	Aspect (degrees)	Slope (%)	Slope Configuration[1]	Slope Position[2]
58	1565	118	36	UN	M
59	1565	108	23	CN	M
60	1465	338	35	UN	R
61	1575	290	38	ST	R
64	1580	146	45	ST	L
65	1620	102	15	ST	M
66	1120	326	30	ST	M
67	1130	335	25	ST	L
68	1125	66	15	UN	B
69	1120	58	10	UN	U
70	1195	325	5	ST	B
71	1235	220	0	ST	B
72	1235	68	10	UN	U
73	1245	88	54	ST	M
74	1245	88	50	ST	M
75	1160	60	35	ST	U
76	1160	96	35	ST	U
77	1430	226	20	ST	U
78	1440	256	20	ST	U
79	1185	48	2	CN	U

[1]Slope Configuration: CV = Convex; CN = Concave; ST = Straight; UN = Undulating.

[2]Slope Position: U = Upper 1/3; M = Middle 1/3; L = Lower 1/3; R = Ridge; B = Bench; S = Stream bottom.

Table 5. Monthly and annual precipitation and mean temperatures for weather stations surrounding the Blue Mountains, Washington.

Station[1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
	Precipitation[2]												
Pomeroy	2.63	1.16	1.44	1.15	1.10	.98	.55	.53	1.14	1.14	1.81	2.17	15.80
Dayton 1	2.89	1.38	1.77	1.49	1.02	1.06	.44	.38	1.07	1.28	2.39	2.69	17.86
Anatone	3.03	1.19	1.61	1.54	1.50	1.70	.94	.77	1.19	1.33	1.91	1.92	18.63
	Mean Temperature (F)[2]												
Pomeroy	34	39	44	49	58	65	72	72	62	52	42	35	52
Dayton 1	33	39	43	48	57	64	71	71	62	51	42	36	52
Anatone	27	33	36	41	50	51	65	65	55	46	36	29	45

[1]Stations are listed by increasing elevation as follows: Pomeroy, 150m; Dayton 1, 475 m; Anatone, 1088 m.

[2]U.S. Weather Bureau 1965-1974. Climatological Data. Washington. Annual Summaries, Asheville, North Carolina.

Table 6. Monthly and annual precipitation and mean temperatures for weather stations surrounding the Clearwater Mountains, Idaho.

Station[1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
	Precipitation[2]												
Fenn Ranger Station	6.34	3.35	4.12	3.72	2.72	3.28	.64	1.10	2.41	3.78	3.90	5.16	40.52
Grangeville 11 SE	2.49	1.31	2.93	3.07	2.42	3.12	.80	1.25	1.84	2.45	2.01	2.28	25.97
Elk City	4.43	2.52	2.57	2.48	2.42	2.84	1.20	1.46	2.04	2.38	2.67	3.82	30.83
	Mean Temperature (F)[2]												
Fenn Ranger Station	29	35	40	46	56	63	70	69	59	47	39	31	49
Grangeville 11 SE	31	36	41	46	55	62	69	69	59	48	39	31	49
Elk City	22	28	31	37	47	56	61	60	48	41	32	23	41

[1]Stations are listed by increasing elevation as follows: Fenn Ranger Station, 483 m; Grangeville 11 SE, 686 m; Elk City, 1237 m.

[2]U.S. Weather Bureau 1966-1975. Climatological Data, Idaho. Annual Summaries, Asheville, North Carolina.

APPENDIX B

OVERSTORY STRUCTURE MEASUREMENTS OF MACROPLOTS

Table 7. Overstory tree data for each plot in the Blue Mountains, Washington.

Plot Number	Sum of the Diameters (m/ha)	Canopy Coverage (%)	Stand Density (# trees/ha)	Basal Area (m^2/ha)	Stand Height (m)
1	110	69	453	36	32
7	332	96	2694	50	24
19	58	35	720	11	16
21	346	85	2000	58	23
26	302	93	1814	56	21
39	147	71	507	39	28
40	154	64	1840	30	26
44	152	78	3174	60	27
45	141	57	640	35	26

Table 8. Overstory tree data for each plot in the Clearwater Mountains, Idaho.

Plot Number	Sum of the Diameters (m/ha)	Canopy Coverage (%)	Stand Density (# trees/ha)	Basal Area (m^2/ha)	Stand Height (m)
58	178	96	853	42	29
59	67	50	453	14	27
60	214	91	1920	30	-[1]
61	195	90	620	17	38
64	147	90	620	46	32
65	166	77	720	46	32
66	186	90	620	49	30
67	209	96	880	46	11
68	141	94	480	35	28
69	161	69	373	17	-[1]
70	172	65	3040	24	34
71	164	96	853	30	17
72	151	90	720	34	24
73	93	76	1334	19	31
74	197	90	1600	41	34
75	110	87	1547	27	34
76	145	84	853	51	-[1]
77	59	50	320	19	22
78	143	95	773	24	20
79	141	71	907	18	20

[1]Incomplete data.

APPENDIX C

MEAN HERBAGE AND BROWSE PRODUCTION SEPARATED BY VEGETATION CLASSES FOR MACROPLOTS

Table 9. Vegetation class production (kg/h) for each plot in the Blue Mountains, Washington.

Plot Number	Total Production	Vegetation Classes				
		Graminoids[1]	Forbs	Low Shrubs[2]	Tall Shrubs[3]	Selected Tall Shrubs[4]
1	312.09	0	202.47	70.87	0	38.8
7	65.42	2.47	52.51	0	0	0
19	591.33	9.29	345.98	111.67	27.93	82.09
21	85.89	0	84.40	0	1.49	0
26	31.20	0	30.73	0.47	0	0
39	355.44	1.44	143.02	141.60	0	69.37
40	321.64	2.84	176.69	65.00	22.84	53.57
44	371.38	0.16	284.22	10.80	0.64	75.56
45	340.33	0	180.58	69.98	5.62	84.16

Table 9. Continued.

Vegetation Classes					
Selected Species					
Vaccinium membranaceum	Acer glabrum	Amelanchier alnifolia	Berberis repens	Lonicera utahensis	Carex species
38.80	0	0	0	0	0
0	0	0	0	0	10.44
82.09	0	0	0	0	14.38
0	0	0	0	0	0
0	0	0	0	0	0
69.22	0.02	0.13	0	0	0
53.33	0	0	0	0.24	0.69
75.56	0	0	0	0	0
84.16	0	0	0	0	0

[1]The vegetation class graminoids excludes the Carex species.

[2]The vegetation class low shrubs excludes Berberis repens.

[3]The vegetation class tall shrubs excludes Acer glabrum, Amelanchier alnifolia and Lonicera utahensis.

[4]The Selected Tall Shrub production is calculated by summing the production of Acer glabrum, Amelanchier alnifolia, Lonicera utahensis and Vaccinium membranaceum.

Table 10. Vegetation class production (kg/h) for each plot in the Clearwater Mountains, Idaho.

Plot Number	Total Production	Vegetation Classes				
		Graminoids	Forbs	Low Shrubs[2]	Tall Shrubs[3]	Selected Tall Shrubs[4]
58	231.49	0	134.53	74.98	2.24	19.74
59	1863.18	0	259.44	1144.47	188.38	269.42
60	421.11	2.13	138.62	221.07	0	59.24
61	1259.82	24.18	291.98	778.44	9.13	117.63
64	305.42	3.42	238.91	27.13	3.27	32.49
65	464.24	0.09	171.36	68.42	32.20	190.89
66	248.18	9.98	206.38	28.11	3.71	0
67	304.82	30.73	242.64	1.20	30.11	.13
68	154.73	9.42	126.20	1.42	16.76	.93
69	546.27	17.89	251.53	68.44	170.49	27.47
70	735.40	24.09	261.16	214.71	109.78	95.57
71	1010.76	27.82	162.29	710.31	62.89	38.07
72	1885.86	35.67	134.24	1614.67	21.33	9.86
73	512.93	123.40	145.09	88.96	133.18	15.74
74	533.15	101.16	164.93	202.13	23.02	27.05
75	316.62	35.69	162.58	5.47	50.87	9.26
76	576.78	144.44	174.42	71.87	102.02	64.43
77	882.76	38.47	255.80	75.31	506.71	3.98
78	256.71	16.33	118.20	2.53	99.76	14.78
79	293.82	10.42	272.87	3.73	3.04	1.47

Table 10. Continued.

Vegetation Classes					
Selected Species					
Vaccinium membranaceum	Acer glabrum	Amelanchier alnifolia	Berberis repens	Lonicera utahensis	Carex species
18.78	0.96	0	0	0	0
196.64	42.53	0.56	0	29.69	1.47
31.42	27.33	0.49	0	0	0.04
95.87	0	0	0	21.76	38.47
27.67	0	0	0	4.82	0.20
189.96	0	0.09	0	0.84	1.29
0	0	0	0	0	0
0	0	0	0	0.13	0
0	0	0.93	0	0	0
16.40	0.89	0	0	9.38	11.24
31.31	0.93	0	23.29	40.04	30.09
28.93	0.42	1.16	0	7.56	9.38
0	0	1.73	0	8.13	70.09
0	5.38	10.36	0	0	6.58
0	0.11	24.56	0	2.38	14.84
0	7.93	0.33	1.00	0	52.76
1.89	10.36	38.96	10.98	2.24	19.60
0	0	3.98	0	0	2.49
13.73	0.07	0.98	0	0	5.11
0	1.47	0	0	0	2.29

[1]The graminoid vegetation class excludes Carex species.

[2]The low shrub vegetation class excludes Berberis repens.

[3]The tall shrub vegetation class excludes Acer glabrum, Amelanchier alnifolia and Lonicera utahensis.

[4]The Selected Tall Shrub production is calculated by summing the production of Acer glabrum, Amelanchier alnifolia, Lonicera utahensis and Vaccinium membranaceum.

Table 11. Original and adjusted[1] production (kg/ha) of vegetation classes for each plot in the Blue Mountains, Washington.

Plot Number	Graminoids		Tall Shrubs	
	Excluding Carex	Including Carex	Excluding Selected Tall Shrubs[2]	Including Selected Tall Shrubs[2]
1	0	0	0	38.8
7	2.47	12.91	0	0
19	9.29	23.67	27.93	110.02
21	0	0	1.49	1.49
26	0	0	0	0
39	1.44	1.44	0	69.37
40	2.84	3.53	22.84	76.41
44	0.16	0.16	0.64	76.20
45	0	0	5.62	89.78

[1]The original and manipulated productions for each vegetation class are located in the right column and left column respectively.

[2]The Selected Tall Shrub species are Acer glabrum, Amelanchier alnifolia, Lonicera utahensis and Vaccinium membranaceum.

Table 12. Original and adjusted[1] productions (kg/ha) of vegetation classes for each plot in the Clearwater Mountains, Idaho.

Plot Number	Total Production		Graminoids		Low Shrubs		Tall Shrubs	
	Including Low Shrubs	Excluding Low Shrubs	Excluding Carex	Including Carex	Excluding Berberis repens	Including Berberis repens	Excluding Selected Tall Shrubs[2]	Including Selected Tall Shrubs[2]
58	231.49	156.50	0	0	74.98	74.98	2.24	21.98
59	1863.18	718.70	0	1.47	1144.47	1144.47	188.38	457.80
60	421.11	200.04	2.13	2.17	221.07	221.07	0	59.24
61	1259.82	481.38	24.18	62.65	778.44	778.44	9.13	126.76
64	305.92	278.29	3.42	3.62	27.13	27.13	3.27	35.76
65	464.24	395.82	0.09	1.38	68.42	68.42	32.20	223.09
66	248.18	220.06	9.98	9.98	28.11	28.11	3.71	3.71
67	304.82	303.62	30.73	30.73	1.20	1.20	30.11	30.24
68	154.73	153.15	9.42	9.42	1.42	1.42	16.76	17.69
69	546.26	477.82	17.89	29.13	68.44	68.44	170.49	197.96
70	735.40	520.35	24.09	54.18	214.71	238.00	109.78	205.35
71	1010.76	300.45	27.82	35.20	710.31	710.31	62.89	100.96
72	1885.87	271.20	35.67	105.76	1614.67	1614.67	21.33	31.19
73	512.93	423.97	123.40	129.98	88.96	88.96	133.18	148.92
74	533.13	331.00	101.16	116.00	202.13	202.13	23.02	50.07
75	316.62	311.15	35.69	88.45	5.47	6.47	50.87	60.13
76	576.78	504.91	144.44	164.04	71.87	82.85	102.02	166.45
77	882.76	807.45	38.47	40.96	75.31	75.31	506.71	510.69
78	256.71	254.18	16.33	21.44	2.53	2.53	99.76	114.54
79	293.82	290.09	10.42	12.71	3.73	3.73	3.04	4.51

[1]The original and manipulated productions for each vegetation class are located in the right column and left column respectively.

[2]The Selected Tall Shrub species are Acer glabrum, Amelanchier alnifolia, Lonicera utahensis and Vaccineum membranaceum.

APPENDIX D

PLANT SPECIES ON EACH STUDY SITE

APPENDIX D

PLANT SPECIES ON EACH STUDY SITE

Plant species (Hitchcock and Cronquist, 1973) that occurred in each vegetation class in the Blue Mountains, Washington

Trees

Abies grandis
Larix occidentalis
Picea engelmanii
Pinus contorta
Pinus ponderosa
Pseudotsuga menziesii

Tall Shrubs

Acer glabrum
Amelanchier alnifolia
Clematis columbiana
Holodiscus discolor
Lonicera utahensis
Physocarpus malvaceous
Prunus virginiana
Phamnus alnifolia
Ribes lacustre
Ribes viscosissium
Rosa gymnocarpa
Rubus parviflorus
Vaccinium membranaceum

Low Shrubs

Berberis repens
Chimaphila menziesii
Chimaphila umbellata
Cornus canadensis
Linnaea borealis
Pyrola asarifolia
Pyrola chlorantha
Pyrola secunda
Pyrola uniflora

Graminoids

Bromus vulgaris
Calamagrostis rubescens
Carex species
Festuca occidentalis
Luzula campestris
Poa compressa
Trisetum canescens

Forbs

Achillea millefolium
Adenocaulon bicolor
Anemone piperi
Antennaria anaphaloides
Antennaria racemosa
Arenaria macrophylla
Arnica cordifolia
Astragalus canadensis
Calochortus elegans
Calypso bulbosa
Circaea alpina
Cirsium vulgare
Clintonia uniflora
Collinsia parviflora
Cystopteris fragilis
Disporum trachycarpum
Epilobium watsonii
Fragaria vesca
Frasera fastigata
Galium aparine
Galium triflorum
Hieracium albiflorum
Listera caurina
Mitella stauropetala
Montia perfoliata
Montia siberica
Osmorhiza chilensis
Penstemon attenuatus
Polemonium pulcherrimum
Polystichum munitum
Ranuculus uncinatus
Satureja douglasii
Sedum lanceolatum
Smilacina stellata
Smilacina racemosa
Synthyris missurica
Thallictrum occidentale
Tiarella trifoliata
Trifolium repens
Valeriana sitchensis
Viola adunca
Viola orgiculata

Plant species (Hitchcock and Cronquist, 1973) that occurred in each vegetation class in the Clearwater Mountains, Idaho.

Trees

Abies grandis
Larix occidentalis
Picea engelmanii
Pinus contorta
Pinus ponderosa
Pseudotsuga menziesii

Tall Shrubs

Acer glabrum
Amelanchier alnifolia
Ceanothus velutinus
Clematis columbiana
Holodiscus discolor
Lonicera ciliosa
Lonicera utahensis
Menziesia ferruginea
Physocarpus malvaceous
Ribes lacustre
Ribes viscosissium
Rosa gymnocarpa
Rubus parviflorus
Salix species
Sorbus scopulina

Low Shrubs

Berberis repens
Chimaphila menziesii
Chimaphila umbellata
Linnaea borealis
Pyrola asarifolia
Pyrola secunda
Pyrola uniflora
Xerophyllum tenax

Graminoids

Bromus vulgaris
Calamagrostis rubescens
Carex species
Festuca occidentalis
Luzula campestris

Forbs

Achillea millefolium
Adenocaulon bicolor
Anemone piperi
Antennaria anaphaloides
Arenaria macrophylla
Asarum caudatum
Astragalus canadensis
Athyrium filix-femina
Calypso bulbosa
Circaea alpina
Cirsium vulgare
Clintonia uniflora
Collinsia parviflora
Coptis occidentalis
Cystopteris fragilis
Disporum trachycarpum
Fragaria vesca
Frasera fastigata
Galium aparine
Galium boreale
Galium triflorum
Hieracium albiflorum
Lathyrus nevadensis
Listera caurina
Mertensia oblongifolia
Mitella stauropetala
Montia siberica
Osmorhiza chilensis
Pedicularis racemosa
Polystichum munitum
Satureja douglasii
Smilacina stellata
Smilacina racemosa
Thallictrum occidentale
Thermopsis montana
Tiarella trifoliata
Trifolium repens
Trillium ovatum
Viola adunca
Viola orbiculata

(attachment to Zamora final report)

Impact on big game habitat:

Tussock moth outbreaks will primarily affect the balance between cover and foraging areas within habitat of big game animals. Impact within a specific unit will be a function of:

(1) the seasonal range in which the outbreak occurred,
(2) severity of stand damage caused by defoliation
(3) amount of damage throughout the unit,
(4) size of each individual damaged area,
(5) uniformity of damage within the stand,
(6) degree of interpersion of damaged stands throughout the unit, and
(7) salvage operations following outbreak.

Where cover is limiting, severe damage to stands which provide critical thermal and hiding cover for animals could have a substantial detrimental impact on big game populations. Where cover is not limiting, severe damage could provide new foraging areas which could substantially benefit populations. In every case, an assessment of the factors listed above is vital to the determination of a realistic impact on a population.

One focus of this study was the determination of forage quantity in stands altered by tussock moth infestations. A majority of the stands examined occur within summer range of elk and deer. Based on Table 8 in the report, the following values were calculated:

degree of damage	allowable forage crop (Kg/ha) 1/	animal unit months per ha 2/	number elk per ha 3/	number deer per ha 3/
severe	379	0.8355	1.25	3.34
moderate	130	0.2866	0.43	1.15
light	117	0.2579	0.39	1.03
undamaged	75	0.1653	0.25	0.66

1/ 50% of the mean current year production for highly and moderately preferred shrubs and all herbaceous plants constitute the allowable forage crop (AFC), this value represents the amount that could be used by animals without damage to the vegetation.

2/ $$\text{AUM} = \frac{\text{area} \times \text{AFC}}{\text{453.59 Kg required to feed 1 animal unit/month}}$$

3/ $$\text{No. animals} = \frac{\text{area} \times \text{AFC}}{453.59 \times \text{number of months on range} \times \text{animal unit equivalent}}$$

animal unit equivalent for elk = 1.5
animal unit equivalent for deer = 4.0

The numbers of animals shown in the above listing are for a 1 month period only.

Calculations based on mean production show a 5-fold increase in the carrying capacity of stands 2-4 years after severe damage caused by tussock moths. It is likely that this increase would last for a 5-15 year period, but would depend entirely on how rapidly the stand developed a overstory of coniferous trees.

Impact on bird populations:

The folloiwng are ideas about the nature of the impact of tussock moth outbreaks on bird populations.

1. Birds which nest in the branches of coniferous trees and that glean coniferous foliage for insects will be detrimentally affected by severe stand defoliation and damage.

2. Certain bird species such as the western tanager, yellow-rumped warbler and kinglets may be detrimentally affected by defoliation of the upper halves of the tree crowns. These and similar species normally occupy that portion of the crown a large percentage of the time.

3. Species of birds that range over the full length of the coniferous tree crown will be less affected by partial crown defoliation.

4. Defoliation that results in severe overstory damage may benefit understory and ground nesting and feeding birds. The lush understory growth will enhance foraging opportunities as well as provide better cover for nesting and security.

5. Bark insect gleaning and cavity nesting birds will be benefited by the increased numbers of snags and trees secondarily infested by insects.

6. Lesser degrees of damage resulting in dead tops and a few additional snags in the stand may create hawking posts for flycatchers which use these sites in foraging activity. In addition, new song posts for other species are created.

7. Defoliation that results in decreased cone production of conifers may affect seed eating birds such as the Evening Grosbeak.

8. Small patches of defoliation that results in patches of snags or more open stands creates diversity which will benefit the bird community of the area in general.